The Annual Convention will be held on board the S.S. Richelieu, September 8, 9, 10 and 11, en route Montreal to Quebec, Saguenay River, etc.

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1924—1925.

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THE ASSOCIATION was organized in Boston, Mass., on June 21, 1882, with the object of providing its members with means of social intercourse and for the exchange of knowledge pertaining to the construction and management of water works. From an original membership of only TWENTY-SEVEN, its growth has prospered until now it includes the names of 800 men. Its membership is divided into six classes, viz:

A Member shall be an officer or employee of a public or private water works, an engineer, chemist or other person qualified to aid or interested in the advancement of knowledge relative to water works.

An Honorary Member shall be a person of acknowledged eminence in some branch of water supply or of engineering.

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An Associate shall be either a person, firm or corporation engaged in manufacturing or furnishing materials or supplies for the construction or maintenance of water works.

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The initiation fees and annual dues are as follows:

Initiation Fees		*Annual Dues*	
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This Association has six regular meetings each year, all of which, except the annual convention in September, are held at Boston.

Table of Contents.

PAGE

The Diesel Engine and Its Overall Economy. By C. B. Jahnke..... 105

Diesel Engine Experience in a Pumping Plant.
By Leonard C. S. Smith..... 135

Diesel Engine Experience in a Modern Forge.
By J. P. Harbeson, Jr..... 138

Discussion of Papers on Diesel Engines..... 141

Color and Other Phenomena of Water from an Unstripped Reservoir in New England. By Caleb Mills Saville..... 145

Some Results of Pipe Cleaning. By Burt B. Hodgman..... 171

Topical Discussion—Protection of Water Pipes and Appurtenances in Exposed Locations..... 174

New England Water Works Association

ORGANIZED 1882.

Vol. XXXIX. June, 1925. No. 2.

This Association, as a body, is not responsible for the statements or opinions of any of its members.

THE DIESEL ENGINE AND ITS OVERALL ECONOMY.

BY C. B. JAHNKE.*

[Read March 10, 1925.]

It is generally admitted and understood by all engineers that the Diesel oil engine is thermodynamically the most efficient prime mover yet developed. The experience of twenty-five years has proved that, in respect to reliability and dependability, it is second to no other form of mechanical power. It remains to be shown that its overall efficiency, taking into account the investment and operating costs, merits the serious thought of power-users when considering replacing steam and electric motor driven plants and in planning for additional power units.

Naturally, the question of the present and future oil supply is a most pertinent one, and it is intended in this paper to throw some light on that subject. Actual operating records, based upon reliable and certified data, should certainly be accepted at their face value and should be fairly comparable with like data on other types of power units. It is not the purpose in this paper to condemn or berate any other form of prime mover, but merely to present some data which will permit an engineer to more readily judge the relative overall efficiency and merit of the Diesel oil engine.

Oil Situation of the United States.

The question of the future oil supply is of especial interest to the prospective as well as the actual Diesel engine owner. Numerous articles have recently been published that will, perhaps, unduly alarm users of oil fuels who have previously given little thought to this subject.

Petroleum.

By referring to Fig. 1 it will be seen that since the beginning of the war there has been a very rapid increase in the amount of petroleum produced and used in the United States. Figure 2 shows the average price per barrel that obtained during this period, and Fig. 3 shows the increasing demand for the various products made from the crude oil.

It appears likely that the demand for oil will continue to increase, at least for a number of years, and that this demand will be met by stabilizing the present industry, by conserving its products, and by the development

* Chief Engineer, Beloit Works, Fairbanks, Morse & Co.

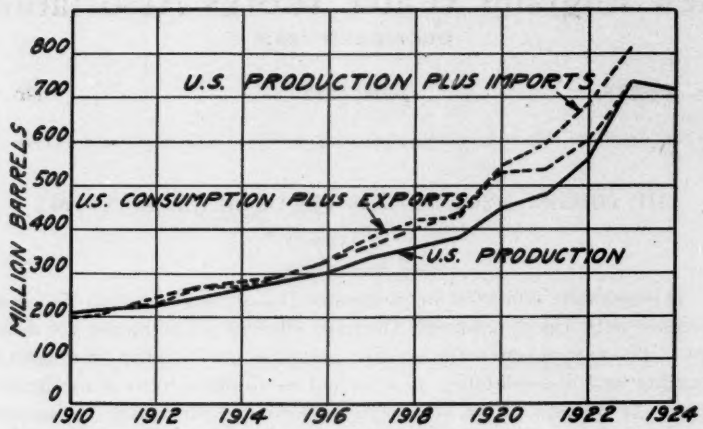

FIG. 1. — ANNUAL PRODUCTION OF CRUDE OIL IN THE UNITED STATES.

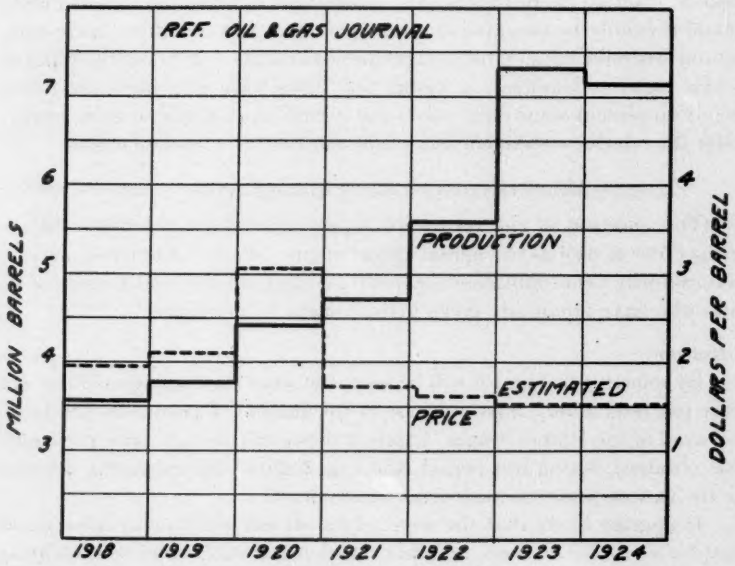

FIG. 2. — PRODUCTION AND PRICE OF DOMESTIC CRUDE OIL.

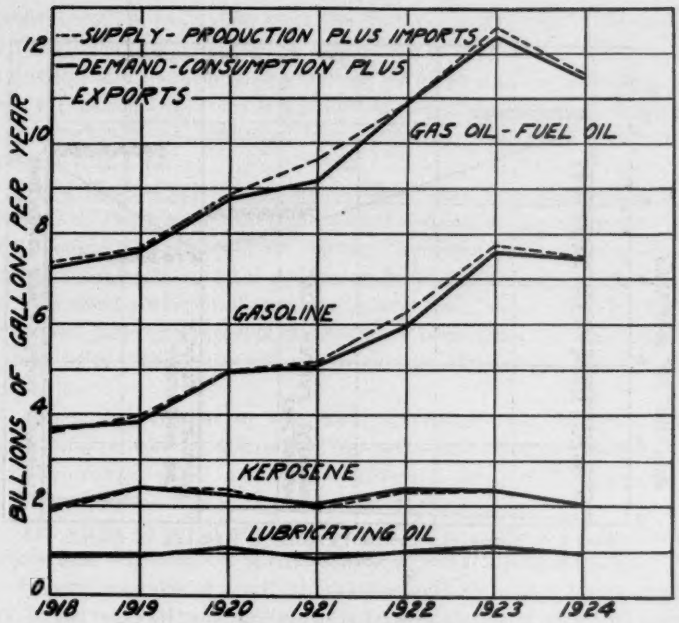

FIG. 3. — REFINERY STATISTICS.

of other sources of supply. Thus far there has been no great incentive for concerted effort along either of these lines, due to the periods of flush production and resulting low price of well oil.

No one knows just how large the remaining petroleum reserves are, although, at various times in the past, attempts have been made to survey them. The estimates that have been made are shown on Fig. 4. It will be seen that each succeeding estimate disagrees with the previous one.

The 1922 survey, made by the U. S. Geological Survey and the American Association of Petroleum Technologists, gave the reserve supply recoverable by existing methods as about nine billion barrels. A joint governmental committee gave the following explanation of the oil situation: "The committee expressly decries the too frequent assumption that inasmuch as the estimated reserves appear to be sufficient to meet the needs of the country at the present rate of consumption for 20 years, therefore the reserves will be exhausted at that time, or, at most, a few years later. This assumption is absolutely misleading, for the oil pools will not all be found within that length of time, drilling will be spread over many years, as the pools are found, and the wells cannot be pumped dry so quickly. Individual wells will yield oil for more than a quarter of a century and some of the wells will not have been drilled in 1950. In short, the oil cannot all be dis-

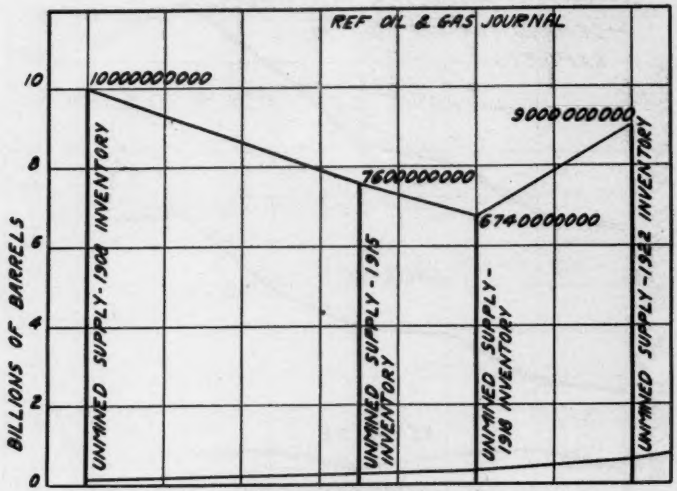

FIG. 4. — ESTIMATED CRUDE PETROLEUM RESERVE IN UNITED STATES.

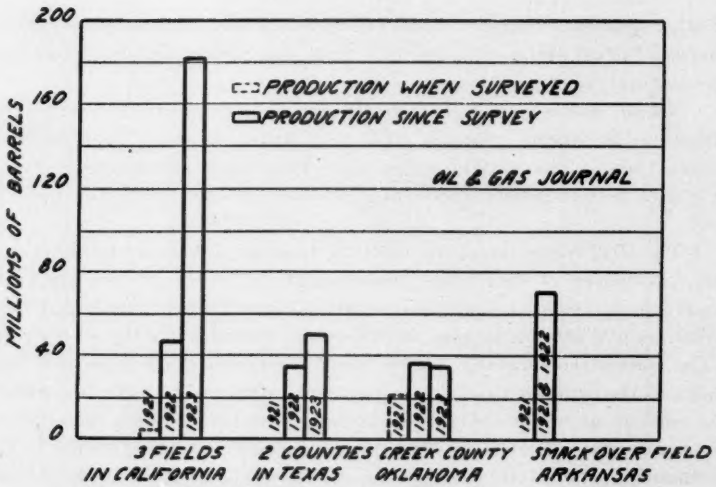

FIG. 5. — PRODUCTION OF CRUDE OIL FROM SEVERAL FIELDS NEW OR UNDISCOVERED WHEN 1922 SURVEY WAS MADE.

covered — much less taken from the earth — in 20 years." Accordingly, the actual result of approaching exhaustion of petroleum will be declining production and increasing dependence on other sources of supply. Just when this change will come is a matter of dispute and depends on what the reserves actually are, and what improvements are made in methods of its production and use.

Since the last survey was made, there have been developments that would likely bring about another upward revision of this estimate. While the geologists who made the survey may have been close to the mark so far as their consideration of the producing fields was concerned, they had no way of knowing what undiscovered or new fields would do. Figure 5 indicates the large quantities of oil that have been obtained from only a few of these fields which were either new or unknown at the time the survey was made.

At the time the survey was made, the Smackover Field in Arkansas was yet undiscovered, but this field has in the past two years produced over 77 million barrels of oil, and is now, after two years of development, outranked by but one field in the United States.

The whole record of production since the last survey has been such as to show that this estimate of recoverable oil was altogether too low.

Present methods of production secure only a comparatively small per cent. of the total oil underground. It is estimated that about 80 per cent. of the original oil content still remains in the ground when the wells are abandoned.

Gasoline.

The greatest demand for gasoline comes from the automobile industry. This increasing demand has been met largely by improved processes such as "cracking," whereby greater percentages of gasoline are obtained from the crude.

In Europe the high price of gasoline forced the adoption of smaller and more efficient engines for use in automobiles. The higher-powered automobile engines used in this country must ultimately be discarded and replaced by more efficient motors. American activity in this direction is evidenced by the research of the General Motors Corporation, Waukesha Motors, and others in the development of more efficient automobile, truck, and tractor engines.

In a recent article J. D. Sears of the U.S. Geological Survey states that an average increase of only 10 per cent. in mileage would mean a saving of more than half a billion gallons of gasoline a year, the equivalent of more than 100 000 barrels of crude oil a day.

Coal and its By-products.

Coal processed under recent improved methods is claimed to be much more economical than raw coal, and it is likely that more and more coal will be processed and that considerable quantities of oil will be secured as by-products. The Ford Motor Company is now trying out such a process at

the River Rouge Plant, and is carbonizing all the coal used in one of its plants. Other manufacturers will, no doubt, do likewise, should the results obtained there show any great economies.

Modern scientific methods of carbonization now perfected will give on the average, from one ton of coal, 3 gal. of motor spirit, 18 gal. of crude dry paraffinoid oils, of which at least 50 per cent. is available for Diesel oil, and other by-products, together with 1 400 lbs. (70 per cent. by weight of the coal) of residual smokeless-burning coke. Considering that our coal reserves are estimated to be sufficient to last about 6 000 years under present production, it can be seen that here lies an immense potential supply of oil. This method is being used very extensively in Europe, particularly in Germany, for the production of tar oil for use in Diesel engines.

If all of the soft coal mined annually in America were processed, enough fuel oil would be available to take care of the present consumption.

Oil-Shale.

The most important future source of supply of oil in this country is the oil shale deposits of our Western States. Shale oil is similar to petroleum and can be made to yield an analogous range of products such as fuel oil, gasoline, lubricating oils, and various by-products.

The U. S. Geological Survey has established the existence of vast areas of shale in Colorado, Utah, Wyoming, Nevada, Kentucky, Indiana, and other states. Much of the shale of the western states is capable of producing about one barrel of oil, 3 000 cu. ft. of gas, and 17 lbs. of ammonium sulphate per ton of shale.

Colorado alone is estimated to contain 1 400 sq. miles, with an average aggregate thickness of 53 ft., and capable of producing at least 20 billion barrels of oil and 300 million tons of ammonium sulphate. The shale deposits of Utah are estimated at some 4 200 sq. miles, capable of yielding about 24 billion barrels of oil. Kentucky alone is estimated to have 100 billion tons of shale available for surface mining and which will yield nearly ½ barrel of oil per ton, plus ammonium sulphate. Indiana is estimated to have 45 million tons of shale, easily accessible for open mining, with much more recoverable by underground mining. Tests of this shale have given an average of 10 gallons per ton.

The estimates of our shale resources indicate that the deposits of this country form a potential supply for oil greater than the total petroleum production to date.

The results obtained in foreign countries, and the tests made in this country, indicate that shale oil is commercially feasible in the United States and is only being held off by the present flush production of petroleum and its resulting low price. To date, the production of shale oil in this country has been largely in the nature of an experiment.

At Elko, Nev., the first shale oil plant in the United States is operating on a commercial basis with a daily production of 100 tons of shale which yields about one barrel to the ton. The results secured have been so sat-

isfactory that the owners have ordered the construction of four more plants in that locality.

In addition to the plant referred to above, there are at least two others now operating on a commercial basis, and others are under construction. Their importance lies not in quantity of oil produced, which totals only a few hundred barrels per day, but in establishing the fact that shale oil can be produced at costs that permit of its sale in competition with well oil, even during this period of its flush production.

In summarizing the fuel situation in the United States, the present-day data, which show the actual and potential sources of oil and coal supply and various means for conservation, indicate that the depletion of the supply of each is interlocked, one with the other, and is beyond estimation.

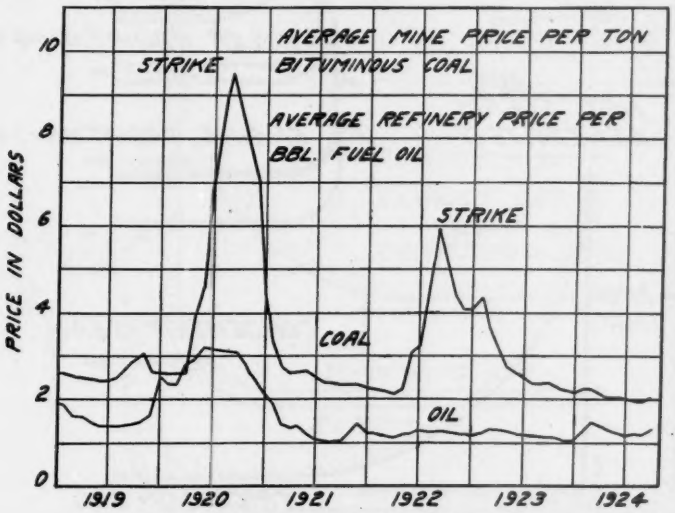

FIG. 6. — COMPARATIVE PRICE OF COAL AND OIL.

The price of oil and coal will continue to strike the established economic balance shown in Fig. 6, based on the interchangeable use of either as sources of heat-production. The natural changing prices of the future will favor the Diesel engine as the prime mover of highest thermal and overall efficiency.

STATUS DIESEL AND STEAM ENGINE EFFICIENCY.

It is not intended simply to recommend the adoption of oil engines wherever power is required, but to study the fields of the steam plant, the motor-driven plant and central station, and the oil-engine plant from the economic standpoint as well as the technical; admitting our responsibility as engineers in the conservation of our natural resources.

Since the first steam engine was built, improvements have been made continuously, until now only about one-fiftieth as much fuel is consumed in producing one h.p. hour as the early engines required. The Diesel engine was first introduced about 30 years ago and since then the fuel consumption has been reduced about 20 per cent.

Figure 7 represents the typical heat balance of a good reciprocating steam-engine plant, or steam turbine machinery of high class, working

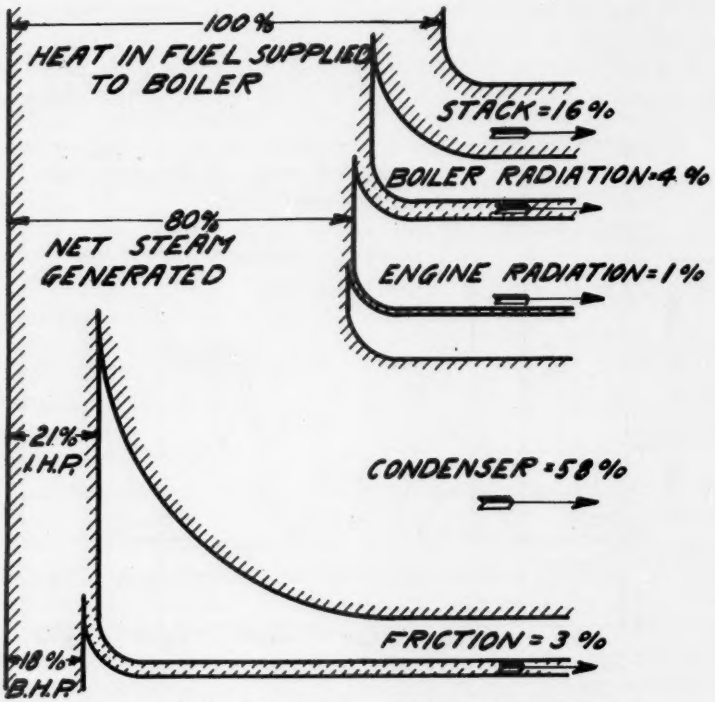

FIG. 7. — TYPICAL HEAT BALANCE OF HIGH CLASS STEAM ENGINE.

under high pressure and a good vacuum provided with superheaters, economizers, feed and air heaters, and all modern heat-saving appliances. The brake thermal efficiency with such equipment may reach 18 per cent. Such results are rarely attained in practice except in very large installations and under most favorable conditions.

Figure 8 shows the heat balance of the most modern Diesel engine, indicating a brake thermal efficiency of 32 per cent. This efficiency is permanent and obtainable in everyday operation, not being influenced by auxiliary equipment such as is common with the usual steam-operated plant under manual control.

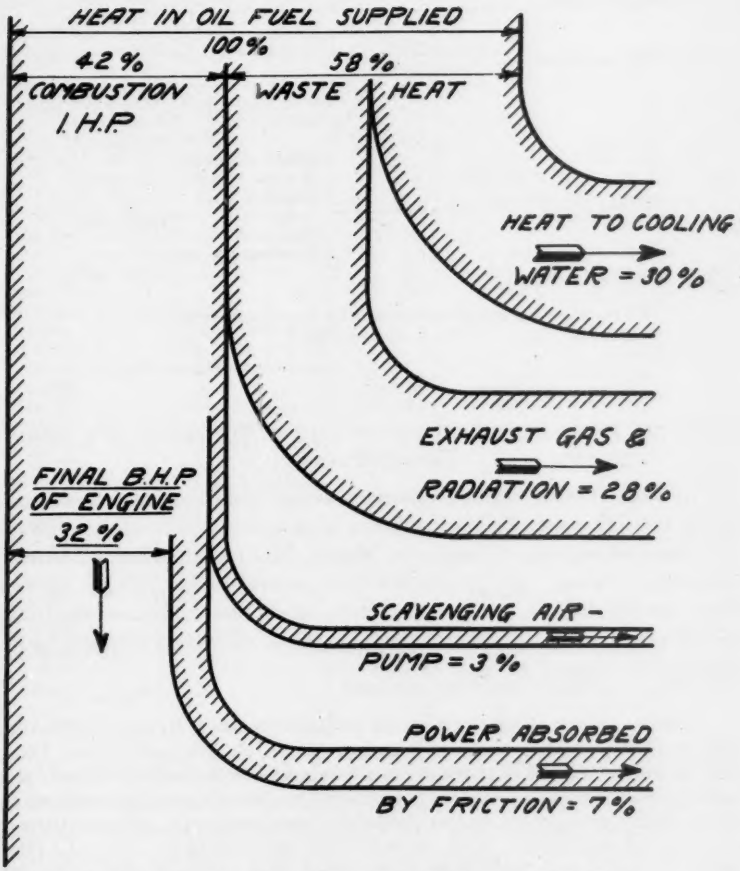

FIG. 8. — TYPICAL HEAT BALANCE OF FAIRBANKS-MORSE & CO. TYPE Y DIESEL ENGINE.

The factors governing the selection of machinery for a power plant or pumping plant, briefly expressed, are shown in Fig. 9.

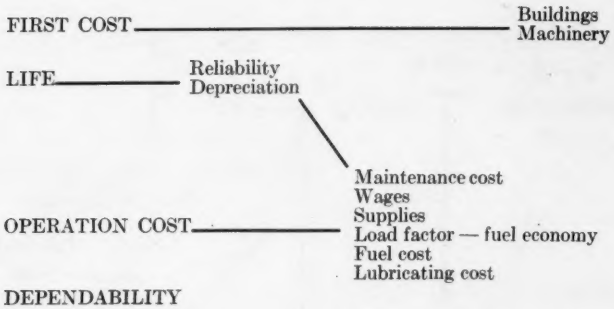

FIG. 9. — FACTORS GOVERNING THE SELECTION OF MACHINERY FOR A POWER PLANT.

ESTIMATED TOTAL COST ANALYSIS OF STEAM, MOTOR, AND OIL ENGINE DRIVEN PLANTS.

In order that we might have independent and disinterested estimates on the relative costs of pumping water with steam power, electric power, and Diesel oil engines, we requested Messrs. Maury & Gordon, Consulting Engineers, Chicago, Ill., to prepare us a general report on that subject. They agreed to do so, subject to certain conditions, and these conditions are embodied in the introductory paragraphs of their report, which read as follows:

"When asked whether we would prepare for you a Report on the relative costs of pumping water with steam power, electric power, and Diesel oil engines, we stated that we should be glad to do so provided, first, that our Report would be general in its character, and would contain no reference, either direct or implied, to the product of any particular manufacturer of any type of machinery; and, second, that the data as to costs and efficiencies on which our conclusions were based were to be secured by us, not from any one manufacturer alone, but were to be based on information available from our own experience and from our office records, supplemented by recent quotations from various makers of the different types of machinery considered, as well as from reliable records of performance in existing plants.

"With this understanding, we have prepared and take pleasure in submitting the following Report:"

Tables 1 to 6, inclusive, and Fig. 10 herewith were prepared by Messrs. Maury & Gordon and formed a part of their report.

TABLE 1.

FIRST COST OF PUMPING EQUIPMENT, AUXILIARIES AND BUILDINGS FOR 12 M.G.D. STATION.

Note: As outlined below, four different types of pumping equipment are considered for this station. In the summary of costs those items have been included which would differ for different types of equipment.

	A	B	C	D
PUMPS:				
(A) 3–12 M.G.D. Horizontal Cross Compound, Condensing, Crank and Fly Wheel	$160 000	....	....	....
(B) 3–12 M.G.D. Steam Turbine Driven Centrifugals	....	$96 000	....	....
(C) 3–12 M.G.D. Motor Driven Centrifugals	....	....	$24 000	....
(D) 3–12 M.G.D. Horizontal Triplex Power Pumps, geared to Oil Engines	....	....	....	$210 000
FOUNDATIONS	3 150	1 800	900	6 750
BOILERS AND ACCESSORIES:				
Boilers, Hand Stokers, Breeching, Boiler Feed Pumps, Foundations, Settings, Instruments and Accessories	33 600	38 500	....	....
STEAM PIPING AND AUXILIARIES	11 000	11 000	....	....
DUPLICATE TRANSMISSION LINE:				
Duplicate Line, Transformers and Wiring	....	....	10 000	....
PIPING FOR COOLING WATER AND OIL	....	....	....	1 000
SIDE TRACK	2 000	2 000	....	2 000
CRANE	7 000	6 100	4 800	7 000
FUEL STORAGE	2 000	2 000	....	2 000
PUMPING STATION BUILDING:				
(A) 417 562 cu. ft. @ $.27	112 742	....	....	....
(B) 394 568 cu. ft. @ .27	....	106 533	....	....
(C) 118 800 cu. ft. @ .30	....	....	35 640	....
(D) 324 576 cu. ft. @ .28	....	....	....	90 881
CONCRETE STACK	5 000	5 000	....	....
Total	$336 492	$268 933	$75 340	$319 631

The three plants considered were for communities of 100 000, 50 000, and 10 000 inhabitants, respectively, and the average per capita daily consumption was assumed to be 120 gal., with a total pumping head of 180 ft. In all cases the necessary reserve stand-by units were included, to comply with the requirements of the Underwriters in respect to additional reserve for fire protection or breakdowns. Tables 1, 2, and 3 give information on total investment. Tables 4, 5, and 6 give itemized operating costs and fixed charges. The prices of coal and oil are current prices for similar localities, and the salaries and the wages are based on present labor conditions that would obtain in towns of respective populations.

The electric-current rates are computed from a schedule of existing rates and provide for a sliding scale of demand charges and energy charges. By applying these rates to the actual maximum demand and output of the

TABLE 2.

FIRST COST OF PUMPING EQUIPMENT, AUXILIARIES AND BUILDINGS FOR 6 M.G.D. STATION.

Note: As outlined below, four different combinations of pumping equipment are considered for this station. In the summary of costs those items have been included which would differ for different combinations of equipment.

	A	B	C	D
PUMPS:				
(A) 2–6 M.G.D. Horizontal Cross Compound, Condensing, Crank and Fly Wheel	$72 000	....	....	....
1–8 M.G.D. Horizontal Cross Compound	45 000	....	....	....
(B) 2–6 M.G.D. Steam Turbine Driven Centrifugals	....	$44 000	....	....
1–8 M.G.D. Steam Turbine Driven Centrifugal	....	26 000	....	....
(C) 2–6 M.G.D. Motor Driven Centrifugals	....	....	$8 000	....
2–4 M.G.D. Gasoline Engine Driven Centrifugals	....	....	13 000	....
(D) 2–6 M.G.D. Oil Engine Driven Duplex or Triplex Pumps	....	....	....	$90 000
2–4 M.G.D. Gasoline Engine Driven Centrifugals	....	....	....	13 000
FOUNDATIONS	2 700	1 200	1 100	3 450
BOILERS AND ACCESSORIES:				
Boilers, Hand Stokers, Breeching, Boiler Feed Pumps, Foundations, Settings, Instruments and Accessories	23 200	25 650	....	....
STEAM PIPING AND AUXILIARIES	6 000	6 000	....	....
PIPING FOR COOLING WATER AND OIL	....	....	....	750
SIDE TRACK	2 000	2 000	....	2 000
CRANE	6 000	5 800	4 800	5 200
FUEL STORAGE	1 600	1 600	400	2 000
PUMPING STATION BUILDING:				
(A) 363 347 cu. ft. @ $.27	98 104	....	....	....
(B) 358 892 cu. ft. @ .27	....	96 901	....	....
(C) 126 000 cu. ft. @ .30	....	....	37 800	....
(D) 216 000 cu. ft. @ .29	....	....	....	62 640
CONCRETE STACK	4 000	4 000	....	....
Total	$260 604	$213 151	$65 100	$179 040

three plants considered, the charges reduce to an equivalent charge of 1.4 cents per kw.-hr. for the 12 million gal. plant, 1.51 cents for the 6 million gal. plant, and 2.1 cents for the 1.2 million gal. plant. The charges for miscellaneous supplies, repairs, interest, and depreciation are based on Maury & Gordon's experience and other available records and information.

Figure 10 shows that for the larger sizes of plants the oil-engine units have economical advantage over the steam and electric units throughout any ordinary range of prices for coal, current, and fuel oil. In the plants of small size, the overall economy becomes remarkably manifest. For example, the total yearly costs per million gal. pumped would, for the 1.2

TABLE 3.

FIRST COST OF PUMPING EQUIPMENT, AUXILIARIES AND BUILDINGS FOR 1.2 M.G.D. STATION.

Note As outlined below, three different combinations of pumping equipment are considered for this station. In the summary of costs those items have been included which would differ for different combinations of equipment.

	A	B	C
PUMPS:			
(A) 2–1.2 M.G.D. Horizontal Cross Compound Non-condensing, Crank and Fly Wheel	$7 000	....	....
1–3.0 M.G.D. Gasoline Engine Driven Centrifugal	5 000	....	....
(B) 2–1.2 M.G.D. Motor Driven Centrifugals	....	$3 000	....
1–3.0 M.G.D. Gasoline Engine Driven Centrifugal	....	5 000	....
(C) 2–1.2 M.G.D. Oil Engine Driven Triplex Pumps	....	....	$20 400
1–3 M.G.D. Gasoline Engine Driven Centrifugals	....	....	5 000
FOUNDATIONS	650	350	1 450
BOILERS AND ACCESSORIES: Boilers, Hand Stokers, Breeching, Boiler Feed Pumps, Foundations, Settings, Instruments and Accessories	7 000	....	....
STEAM PIPING AND AUXILIARIES	1 000	....	....
PIPING FOR COOLING WATER AND OIL	....	....	300
SIDE TRACK	2 000	....	2 000
CRANE	2 500	1 800	2 400
FUEL STORAGE	1 000	400	1 600
PUMPING STATION BUILDING:			
(A) 80 220 cu. ft. @ $.29	23 264	....	....
(B) 22 848 cu. ft. @ .40	....	9 139	....
(C) 38 640 cu. ft. @ .35	....	....	13 524
STACK	1 500	....	....
TOTAL	$50 914	$19 689	$46 674

million gal. plant be much less for the oil-engine plant than for the steam plant, even though the price of coal were only $2.00 per ton and one had to pay 10 cents per gallon for fuel oil. For the small plant the yearly cost per million gal. pumped for oil-engine plants, with oil at 6 cents, would be just about equal to cost for electric plants with current at 1 cent per kw.-hr. inclusive of demand and energy charges. It is unlikely that so low a rate for current could ever be obtained for so small a plant.

From the data given in Fig. 10 we have plotted curves for Diesel, steam, and motor driven pumping plants, bringing out perhaps a little more clearly the cost comparisons at various fuel and current prices. These curves are shown in Fig. 10a.

TABLE 4.

OPERATING EXPENSES AND FIXED CHARGES FOR DIFFERENT TYPES OF EQUIPMENT FOR 12 M.G.D. PUMPING STATION.

	A	B	C	D
LABOR:				
Chief Engineer @ $3 000	$3 000	$3 000	$3 000	$3 000
Assistant Engineers @ 2 100	6 300	6 300	6 300	10 500
Firemen @ 1 800	10 800	10 800	....	....
FUEL: (Based on average pumpage of 12 M.G.D.)				
(A) 3 478 tons of coal (145 000 000 ft. lb. duty and 7 lb. evaporation) @ $4.50	15 651	....	....	....
(B) 4 188 tons of coal (112 000 000 ft. lb. duty and 7 lb. evaporation) @ $4.50	....	18 846	....	....
(C) 3 686 208 kw.-hr. (67% overall efficiency) @ 1.4c.	....	....	51 607	....
(D) 261 905 gal. fuel oil (.50 lb. per B.H.P. hour, 85% pump efficiency) @ 5c.	....	....	....	13 095
CYLINDER OIL, LUBRICATING OIL AND WASTE	350	600	200	1 800
MAINTENANCE AND REPAIRS:				
Machinery and Equipment:				
(A) $204 600 @ 1.5%	3 069	....	....	....
(B) 145 500 @ 1.7%	....	2 473	....	....
(C) 34 000 @ 1.5%	....	....	510	....
(D) 211 000 @ 1.9%	....	....	....	4 009
Buildings, Chimney, Foundations, Side Track, Crane, Coal and Fuel Storage				
(A) $131 892 @ 0.5%	659	....	....	....
(B) 123 433 @ 0.5%	....	617	....	....
(C) 41 340 @ 0.5%	....	....	207	....
(D) 108 631 @ 0.5%	....	....	....	543
SUB TOTAL	$39 829	$42 636	$61 824	$32 947

INTEREST AND DEPRECIATION

Machinery and Equipment:	Int.	Rate. Depr.	Total				
(A) $204 600	5%	1.9%	6.9%	$14 117	....	....	....
(B) 145 000	5%	3.36%	8.36%	....	$12 164	....	....
(C) 34 000	5%	2.5%	7.50%	....	....	$2 500	....
(D) 211 000	5%	3.0%	8.0%	....	....	....	$16 880
Buildings, etc.:							
(A) $131 892	5%	0.8%	5.8%	7 650	....	....	....
(B) 123 433	5%	0.8%	5.8%	....	7 159	....	....
(C) 41 340	5%	0.8%	5.8%	....	....	2 398	....
(D) 108 631	5%	0.8%	5.8%	....	....	....	6 301
SUB TOTAL				$21 767	$19 323	$4 948	$23 181
TOTAL				$61 596	$61 959	$66 772	$56 128

TABLE 5.

YEARLY OPERATING EXPENSES AND FIXED CHARGES FOR DIFFERENT TYPES OF EQUIPMENT FOR 6 M.G.D. PUMPING STATION.

	A	B	C	D
LABOR:				
Chief Engineer @ $2 700.....	$2 700	$2 700	$2 700	$2 700
Assistant Engineers @ 2 000.....	6 000	6 000	6 000	8 000
Firemen @ 1 700.....	6 800	6 800	....	....
FUEL: (Based on average pumpage of 6 M.G.D.)				
(A) 1 831 tons of coal (138 000 000 ft. lb. duty and 6½ lb. evaporation) @ $4.50	8 240	....	....	....
(B) 2 408 tons of coal (105 000 000 ft. lb. duty and 6½ lb. evaporation) @ $4.50	....	10 836	....	....
(C) 1 900 044 kw.-hr. (65% overall efficiency) @ 1.51c.....	....	....	28 690	....
(D) 136 188 gal. fuel oil (.52 lb. per B.H.P., 85% pump efficiency) @ 5c.....	....	....	....	6 809
CYLINDER OIL, LUBRICATING OIL AND WASTE	250	450	200	1 250
MAINTENANCE AND REPAIRS:				
Machinery and Equipment:				
(A) $146 200 @ 1.5%	2 193	....	....	....
(B) 101 650 @ 1.7%.....	....	1 728	....	....
(C) 21 000 @ 1.6%.....	....	....	336	....
(D) 103 750 @ 2.0%.....	....	....	....	2 075
Buildings, Chimney, Foundations, Side Track, Crane, Coal and Fuel Storage:				
(A) $114 404 @ 0.5%.....	572	....	....	....
(B) 111 501 @ 0.5%.....	....	558	....	....
(C) 44 100 @ 0.5%.....	....	....	221	....
(D) 75 290 @ 0.5%.....	....	....	....	376
SUB TOTAL.....	$26 755	$29 072	$38 147	$21 210

INTEREST AND DEPRECIATION.

Machinery and Equipment:	Rate Int.	Depr.	Total				
(A) $146 200	5%	1.9%	6.9%	$10 088	....	....	....
(B) 101 650	5%	3.36%	8.36%	....	$8 498	....	....
(C) 21 000	5%	2.8%	7.8%	....	....	$1 638	....
(D) 103 750	5%	3.2%	8.2%	....	....	....	$8 508
Buildings, etc.:							
(A) $114 404	5%	0.8%	5.8%	6 635	....	....	....
(B) 111 501	5%	0.8%	5.8%	....	6 467	....	....
(C) 44 100	5%	0.8%	5.8%	....	....	2 558	....
(D) 75 290	5%	0.8%	5.8%	....	....	....	4 367
SUB TOTAL.				$16 724	$14 965	$4 196	$12 875
TOTAL.....				$43 478	$44 037	$42 343	$34 085

TABLE 6.

YEARLY OPERATING EXPENSES AND FIXED CHARGES FOR DIFFERENT TYPES OF EQUIPMENT FOR 1.2 M.G.D. PUMPING STATION.

	A	B	C
LABOR:			
Chief Engineer @ $2 100	$2 100	$2 100	$2 100
Assistant Engineers @ 1 620	3 240	3 240	1 620
Firemen	4 200	....	....
Helper	....	....	1 200
FUEL: (Based on average pumpage of 1.2 M.G.D.)			
(A) 993 tons of coal (60 000 000 ft. lb. duty and 5½ lb. evaporation) @ $4.50	4 468	....	....
(B) 392 098 kw.-hr. (63% overall efficiency) @ 2.1c	....	8 234	....
(C) 29 506 gal. fuel oil (.55 lb. per B.H.P., 83% pump efficiency) @ 5c	....	....	1 475
CYLINDER OIL, LUBRICATING OIL AND WASTE	100	75	250
MAINTENANCE AND REPAIRS:			
Machinery and Equipment:			
(A) $20 000 @ 1.5%	300	....	....
(B) 8 000 @ 1.6%	....	128	....
(C) 25 700 @ 2.0%	....	....	514
Buildings, Chimney, Foundations, Side Track, Crane, Coal and Fuel Storage:			
(A) $30 914 @ 0.5%	155	....	....
(B) 11 689 @ 0.5%	....	58	....
(C) 20 974 @ 0.5%	....	....	105
SUB TOTAL	$14 563	$13 835	$7 264

INTEREST AND DEPRECIATION.

	RATE.					
Machinery and Equipment:	Int.	Depr.	Total			
(A) $20 000	5%	1.9%	6.9%	$1 380	....	....
(B) 8 000	5%	2.8%	7.8%	....	$624	....
(C) 25 700	5%	3.2%	8.2%	....	....	$2 107
Buildings, etc.:						
(A) $30 914	5%	0.8%	5.8%	1 793	....	....
(B) 11 689	5%	0.8%	5.8%	....	678	....
(C) 20 974	5%	0.8%	5.8%	....	....	1 216
SUB TOTAL				$3 173	$1 302	$3 323
TOTAL				$17 736	$15 137	$10 587

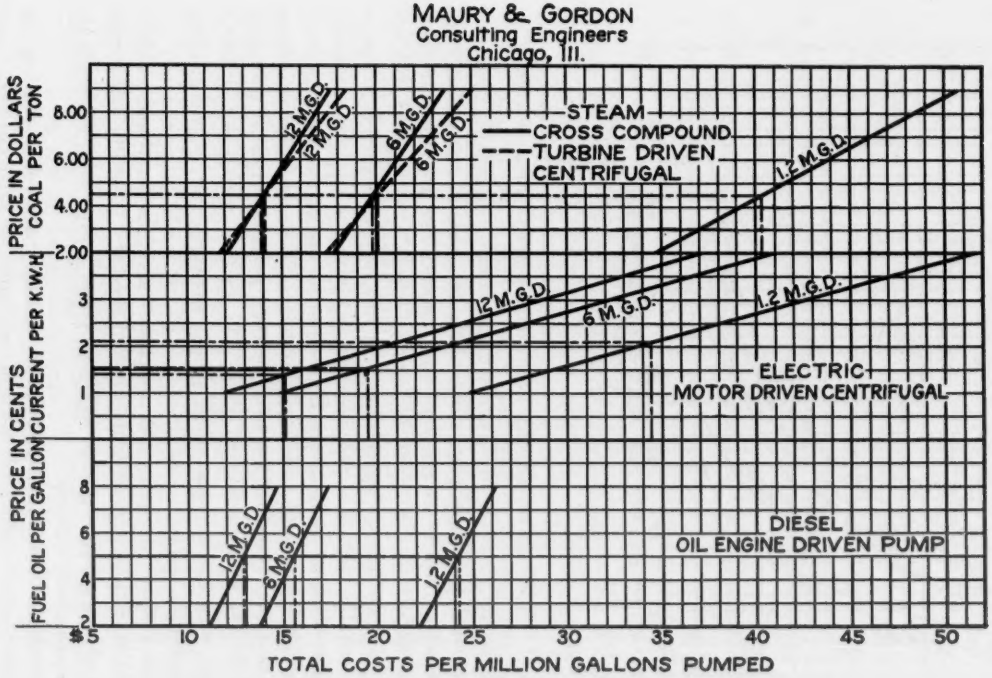

FIG. 10. — TOTAL COSTS PER MILLION GALLONS PUMPED.

Note: These costs include operating expenses and they also include fixed charges on all items which are not practically the same for all plants of the same capacity.

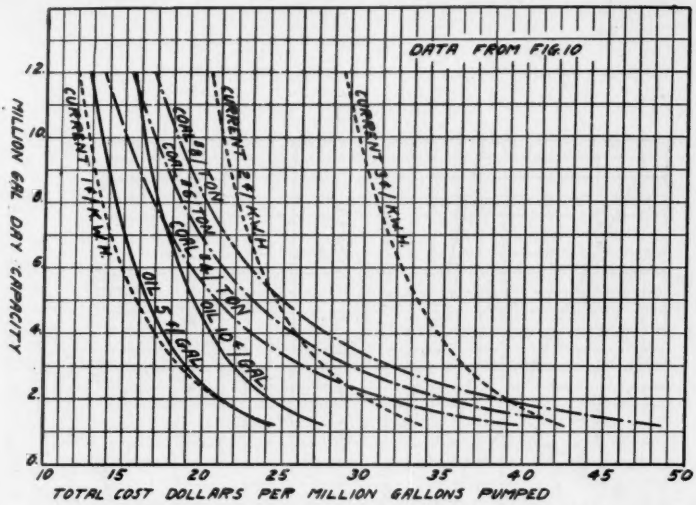

FIG. 10A. — COMPARATIVE TOTAL COSTS OF STEAM, MOTOR, AND OIL ENGINE PUMPING PLANTS.

ACTUAL OIL ENGINE PLANT OPERATING COSTS.

It is rather difficult to secure a great number of reliable operating figures on small municipal plants, due to the fact that in many cases complete operating records are not kept, or, if most of the items are recorded, some one important factor will be entirely overlooked; so that it is impossible to draw definite conclusions. It has been endeavored to secure as many reliable records as possible, and as a result of that investigation, we are able to show some detailed costs on the operation of twenty-nine plants in municipal light and power service. These records are perhaps not the best that could be secured, but they probably represent average practice for the small municipal plant, and for that reason can be safely compared with the average small plant operating with steam or purchased power.

Table 7 shows the principal equipment which is contained in these twenty-nine stations and gives the class of service. It will be noted that fourteen are operated on electric light and power service and the others are classed as pumping stations.

Records on oil used show that the average cost of fuel in all of the plants under consideration was 5.4 cents per gallon or $2.16 per barrel, and the average cost of lubricating oil was 55.9 cents per gallon during the year 1923.

The next important item in the operation of a power or pumping plant is the operating labor which is required. This operating labor cost is partly dependent on the yearly load factor of the plant and on the number of units

TABLE 7.

LOCATION AND EQUIPMENT OF TWENTY-NINE OIL ENGINE DRIVEN PLANTS WHICH WERE ANALYZED.

1. New England, No. Dak. Municipal elec. light and power. 1–50 h.p. D.C. to 40 kv.a. 2 300 v. alternator. 1–100 h.p. D.C. to 75 kv.a. 2 300 v. alternator.
2. Dakota Utilities Co., Eureka, So. Dak. Central station. 1–100 h.p. D.C. to 72 kw. alternator. 1–50 h.p. belt connected to 30 kw. alternator: 1–25 h.p. belt connected to 20 kw. alternator. Three phase, 60 cycle, 2 300 v.
3. Pender, Nebr. Municipal elec. light and power. 1–100 h.p. D.C. to 75 kv.a. alternator. 1–150 h.p. D.C. to 125 kv.a. alternator. Three phase, 60 cycle, 2 300 v. alternators.
4. Oakland, Nebr. Municipal pumping. 1–50 h.p. belt connected to 2–24 x $7\frac{1}{16}$ in. deep well pumps and 1–24 x $5\frac{1}{2}$ in. deep well pump and 1–8 x 10 in. triplex 274 g.p.m.
5. Storm Lake, Ia. Municipal pumping. 1–$37\frac{1}{2}$ h.p. geared to 10 x 12 in. triplex belted to 6 in. centrifugal.
6. Perry, Ia. Municipal pumping. 2–100 h.p. D.C. to 60 kw. Two phase, 60 cycle, 230 v. alternators. 3–25 h.p. motors D.C. to 3–400 g.p.m. centrifugal pumps.
7. Bancroft, Nebr. Municipal light and power. 2–50 h.p. belted to $37\frac{1}{2}$ kv.a. Three phase, 60 cycle, 2 300 v. alternator.
8. Emerson, Nebr. Municipal light and power. 1–$37\frac{1}{2}$ h.p. belted to 25 kw. alternator. 1–50 h.p. belted to $37\frac{1}{2}$ kw. alternator. 1–150 h.p. D.C. to a 125 kv.a. alternator. Alternators three phase, 60 cycle, 2 300 v.
9. Natchitoches, La. Municipal pumping. 2–150 h.p. each D.C. to 125 kv.a. Three phase, 60 cycle, 2 300 v. alternator and clutch connected to 750 g.p.m. duplex power pumps.
10. Gallipolis, O. Municipal pumping. 1–100 h.p. belt connected to a 11 x 14 in. triplex pump at 42 r.p.m.
11. Watsonville Ice and Cold Storage Co., Watsonville, Cal. 1–50 h.p. belt connected to a 25-ton ammonia comp.
12. Jas. Rosenberg, San Arde, Cal. Irrigation. 1–100 h.p. 12 in. belt connected to a 5 400 g.p.m. centrifugal pump.
13. Quincy, Mich. Municipal light, power and pumping. 1–100 h.p. D.C. to 75 kv.a. and 1–200 h.p. D.C. to 170 kv.a. alternators. Two phase, 60 cycle, 1 150 v. 1 000 g.p.m. and 350 g.p.m. and 175 g.p.m. centrifugals.
14. Santa Cruz, Cal. Municipal pumping. 1–100 h.p. belted to 800 g.p.m. centrifugal and 1–150 h.p. belted to centrifugal.
15. Madill, Okla. Municipal pumping. 1–75 h.p. D.C. to 9 x 12 in. single acting triplex and 1–75 h.p. D.C. to 9 x 12 in. triplex and 5 x 5 in. single stage air compressor.
16. Fayetteville, Ark. Water Improvement District No. 1. 1–150 h.p. clutch connected to 10 x 16 in. triplex pump.
17. Strawn, Texas. Municipal light and power. 2–50 h.p. D.C. to 40 kv.a. alternator. 1–150 D.C. to 125 kv.a. alternator.
18. Roodhouse, Ill. Roodhouse Water Corporation. 1–75 h.p. D.C. to 11 x 12 in. triplex pump.
19. Tirrill, Texas. Municipal light and power. 3–200 h.p. D.C. to 170 kv.a. 1–300 h.p. D.C. to 250 kv.a. alternator.
20. Garland, Texas. Municipal elec. light and power. 2–100 h.p. D.C. to 75 kv.a. and 1–150 h.p. to 125 kv.a. alternator.
21. Nicholasville, Ky. Municipal pumping. 1–100 h.p. D.C. to 7 x 12 in. 450 g.p.m. duplex pump and belted to 14 x 9 in. compressor.

22. Stonewall, Okla. Municipal elec. light. 2–50 h.p. D.C. to 40 kv.a. Three phase, 60 cycle, 2 300 v. alternators.
23. Vinalhaven, Me. Vinalhaven Elec. Light and Power Company. 1–50 h.p. D.C. to 32 kw. and 1–25 h.p. belted to 16 kw. alternators.
24. Covington, Tenn. Municipal elec. light and power. 1–100 h.p. D.C. to 75 kv.a. 1–200 h.p. to 170 kv.a. and 1–300 h.p. to 250 kv.a. Three phase, 60 cycle, 2 300 v. alternators.
25. Charleston, Miss. Municipal water and light plant. 1–100 h.p. D.C. to 75 kv.a., and 1–200 h.p. to 170 kv.a.
26. Crystal Falls, Texas. Walker Caldwell Water Co. 1–50 h.p. belted to 625 g.p.m. centrifugal. 1–100 h.p. D.C. to 1 000 g.p.m. centrifugal.
27. Newton, Miss. Municipal light and water. 1–50 h.p. D.C. to 40 kv.a. alternator and fire pump. 1–100 h.p. D.C. to 75 kv.a. alternator and fire pump. 1–150 h.p. D.C. to 125 kv.a. alternator.
28. Woodsfield, O. Municipal light and power. 2–200 h.p. D.C. to 170 kv.a. Three phase, 60 cycle, 2 300 v. alternators.
29. H. R. Brown & Son Coal Co., New Philadelphia, Ohio. 1–100 h.p. belted to 80 kw. 250 v. D.C. generator.

Note: D.C. where used after engine means direct connected.

TABLE 8.

OPERATING LABOR COSTS IN OIL ENGINE PLANTS OF TABLE 7.

Plant No.	No. Units.	Total H. P.	Hours Service Per Day.	Total Engine Hrs. per yr. all units.	Number Attendants.	Total Labor Cost Dollars.	Location.
1.....	2	150	24	7 552	2	$3 000	N. D.
2.....	3	175	24	11 315	3	3 900	S. D.
3.....	2	250	24	....	3	4 800	Neb.
4.....	1	50	10	3 650	1	2 160	Neb.
5.....	1	37½	14	4 750	1	1 620	Ia.
6.....	2	200	24	8 800	3	3 440	Ia.
7.....	2	100	24	8 395	2	2 400	Neb.
8.....	3	237½	24	10 030	3	4 320	Neb.
9.....	2	300	24	8 459	3	4 320	La.
10.....	1	100	12	4 380	1	1 900	Ohio
11.....	1	50	24	8 010	1*	1 200	Cal.
13.....	2	300	24	8 760	3	4 440	Mich.
14.....	2	250	24	6 200	3	2 270	Cal.
15.....	2	150	8	2 920	1	1 200	Okla.
16.....	1	150	24	6 570	2	1 740	Ark.
17.....	3	250	24	14 620	3	4 800	Tex.
18.....	1	75	..	....	2	3 000	Ill.
19.....	4	900	24	....	4	5 760	Tex.
20.....	3	350	24	....	2	2 820	Tex.
21.....	1	100	8	2 920	1	900	Ky.
22.....	2	100	24	10 220	2	2 400	Okla.
23.....	2	75	10	4 350	2	2 500	Maine
24.....	3	600	24	5 760	3	2 310	Tenn.
25.....	2	300	24	12 000	2	2 010	Miss.
26.....	2	150	24	5 923	2	3 206	Tex.
27.....	3	300	24	12 720	2	2 300	Miss.

*One man on each shift operates ice plant.

which are installed. It naturally follows that a plant which operates sixteen hours out of the day will require more operating expense than one which operates eight hours per day, and it also follows that a plant containing three or four units will require more care and, therefore, more expense than a single unit plant.

Table 8 shows a tabulation covering twenty-seven plants on the basis of the operating labor costs, and also includes such items as the hours service per day, the total engine hours operated per year, the number of attendants, and the location.

There are eight single-unit plants shown in the tabulation and the average labor cost is $1 565 per year. The twelve two-unit plants averaged $2 999 and the six three-unit plants averaged $3 408. Only one four-unit plant is operated and the labor cost is entered at $5 760.

The average labor cost per man is approximately $1 500 per year.

Labor costs, of course, depend somewhat on geographical location and there will be some variation in different plants for that reason. It will be noted, however, that it would hardly be possible to reduce any of these labor charges, as in many cases the single-unit plants are operated by one man, and even the three-unit plants require only three men when operated

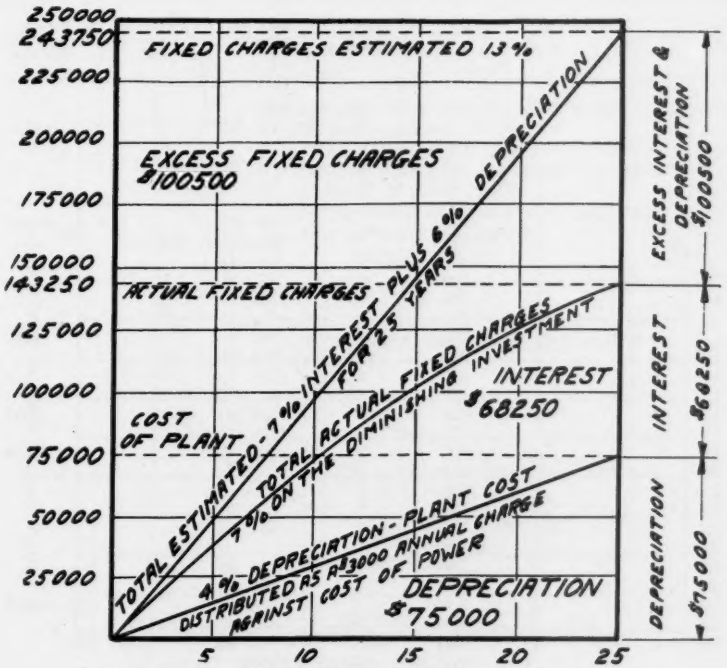

FIG. 11. — EXCESS FIXED CHARGES AS USUALLY ESTIMATED ON DIESEL ENGINE PLANTS BASED ON $75,000 FIRST COST.

TABLE 9.

SINKING FUND, EXPRESSED AS A PERCENTAGE OF FIRST COST.

Life, Years.	RATE OF COMPOUND INTEREST.		
	5	6	7
20	$3.02	$2.72	$2.44
25	2.10	1.82	1.58
30	1.50	1.26	1.06

on a twenty-four-hour basis, or one man per shift. These figures, therefore, tend to disprove the contention of the advocates of motor drive, — that the cost of labor is higher on the oil-engine plant than it is on the motor-operated plant. One man has to be kept on the job regardless of the type of plant, and it is evident from these figures that one man can handle an oil-engine plant of considerable size.

TABLE 10.

AN ANALYSIS OF REPAIR COSTS IN THE OIL ENGINE PLANTS OF TABLE 7.

Plant No.	No. Units.	Total H. P.	Years Service.	Total Cost Engine Repairs.	Extra Labor Cost.	Repairs per Unit Produced
1	2	150	1½	....	....	....
2	3	175	8	$2 506.00	....	$.00024
3	2	250	1	....	....	....
4	1	50	2	0.84	....	....
5	1	37½	3	....	....	....
6	2	200	1	....	....	....
7	2	100	6	1 007.68	....	.00016
8	3	237½	5	980.88	$40.00	....
9	2	300	4	150.00	....	....
10	1	100	1½	65.00	50.00	....
11	1	50	10	265.00	....	....
12	1	100	4	....	....	....
13	2	300	4	785.00	....	.0005
14	2	250	8	368.00	....	....
15	2	150	4	51.51	50.00	....
16	1	150	1½	....	....	....
17	3	250	10	6 293.00*	....	.0012
18	1	75	3	249.03	....	....
19	4	900	2	605.15	....	.00024
20	3	350	1	....	....	....
21	1	100	1	....	....	....
22	2	100	6	750.00	....	....
23	2	75	6	1 554.12	....	....
24	3	600	1	....	....	....
25	2	300	1	21.65	....	....
26	2	150	4	527.67	....	....
27	3	300	4	308.46	....	.00027
28	2	400	2	414.90	523.98	....
29	1	100	3	54.04	....	....

*Crankshaft

On account of its fairly high first cost, it has been claimed that the fixed charges on a Diesel engine are necessarily extremely high. A good oil engine maintained in regard to the wearing elements will last indefinitely. Experience indicates that the parts which require care and maintenance are common to all prime movers. Records available through the British Diesel Engine Users Association, and American Records obtained during the last 20 years, indicate that useful life of a modern Diesel engine can with the utmost safety and conservatism be set at 25 years. The obsolescence figure in depreciation of the Diesel engine is negligible. It is extremely essential that the amount of actual depreciation be most carefully determined.

Figure 11 shows that the total yearly interest on the cash outlay becomes less each year, as the amount originally invested is reduced by the yearly depreciation. Therefore, fixed detailed percentage rates cannot justly be assumed. Arbitrary rates of fixed charges, including interest, depreciation, and insurance, have often been set as high as 13 to 15 per cent.

A suggested method in determining the fixed charges against the investment is to add to a liberal interest rate, shown in Table 9, instead of a fixed depreciation rate, that percentage of the initial investment set aside as a sinking fund and which at interest compounded annually will aggregate

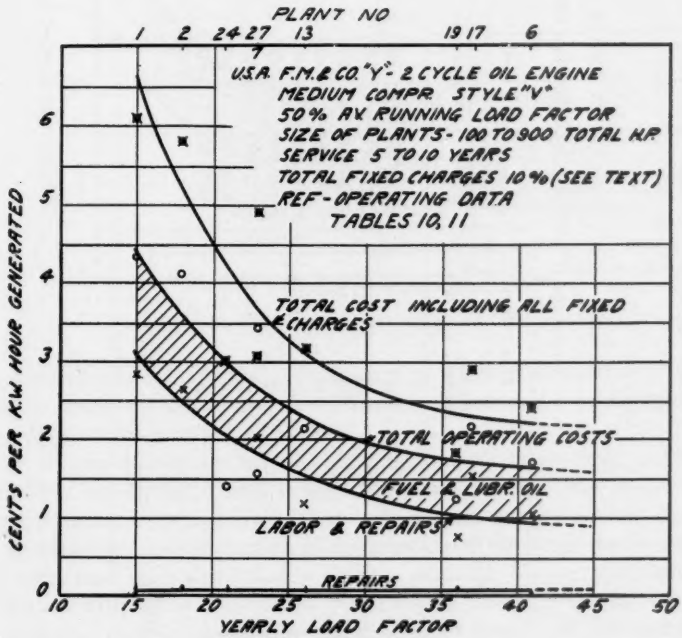
PLANT NO
1 2 24 27 13 19 17 6
U.S.A. F.M.E. CO. "Y" - 2 CYCLE OIL ENGINE
MEDIUM COMPR. STYLE "V"
50% AV. RUNNING LOAD FACTOR
SIZE OF PLANTS - 100 TO 900 TOTAL H.P.
SERVICE 5 TO 10 YEARS
TOTAL FIXED CHARGES 10% (SEE TEXT)
REF - OPERATING DATA
TABLES 10, 11
TOTAL COST INCLUDING ALL FIXED & CHARGES
TOTAL OPERATING COSTS
FUEL & LUBR. OIL
LABOR & REPAIRS
REPAIRS
CENTS PER K.W. HOUR GENERATED
0 1 2 3 4 5 6
10 15 20 25 30 35 40 45 50
YEARLY LOAD FACTOR

FIG. 12. — UNIT COST ANALYSIS.

TABLE 11.

OPERATING COSTS OF THE OIL ENGINE DRIVEN ELECTRIC PLANTS OF TABLE 7.

Plant No.	Load Factor.		Units Produced Per Year. Kw.-hr.	Operating Cost.		Total Investment.	Fixed Charge Cost.		Unit Fuel and Lubricating Oil Cost.	Unit Total cost with fixed Charges.
	Running Plant %.	Yearly Plant %.		Total.	Unit.		Total.	Unit.		
1	37½	15	113 605	$4 929	$.0434	$19 800	$1 980	$.0174	$.016	$.0608
2	42	18	165 050	6 787	.0411	36 300	3 630	.0220	.0147	.0631
6	82	41	430 000	7 320	.0170	30 000	3 000	.0070	.0066	.0240
7	48	23	120 000	4 080	.0340	18 200	1 820	.0152	.0140	.0490
13	52	36	403 000	8 497	.0210	41 000	4 100	.0102	.0094	.0312
17	58	37	481 800	10 309	.0214	34 400	3 440	.0071	.0079	.0285
19	..	36	1 271 400	15 224	.0120	74 400	7 440	.0058	.0074	.0178
24	57	21	650 000	10 236	.0157	92 000	9 200	.0141	.008	.0298
27	38	23	365 000	5 648	.0155	54 000	5 400	.0148	.009	.0303
Average					$.0246			$.0124	$.0103	

the original cash investment at the end of the estimated life of the equipment.

Example: 7 per cent. — Interest.
1.58 per cent. — Depreciation 25 years compounded.
1.5 per cent. — Insurance.
Approx. 10 per cent. plus = Total fixed charges.

It would be entirely fair for strictly municipal plants to use an interest rate of 5 per cent., which would have the effect of further reducing the fixed charges.

Figure 12 shows detailed unit costs taken from tables of electric power plants having approximately 50 per cent. running loads factor. It is

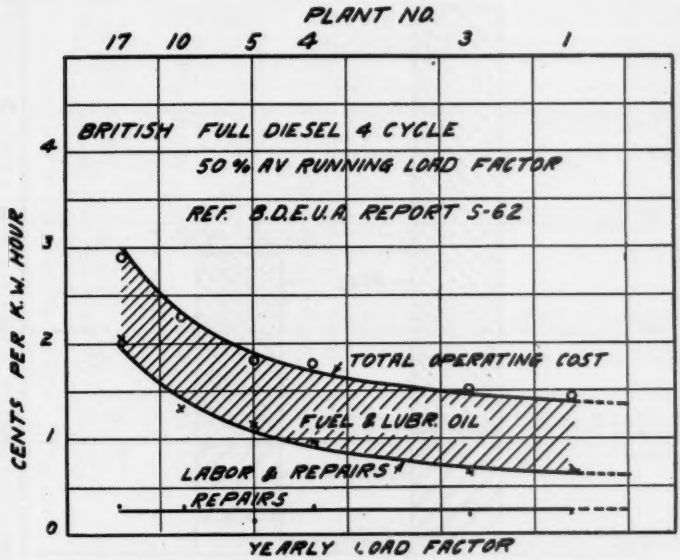

FIG. 13. — UNIT COST ANALYSIS OF ELECTRIC PLANTS.

interesting to note the very low repair item which is distinctive of the two-cycle simple oil engine and the uniformity of fuel and lubricating oil cost, irrespective of yearly load factor.

Figure 13 is made up of operating records taken from publication S-62 of the British Diesel Engine Users Association. The initial investment figures were not given, so it is impossible to show overall unit cost. Nevertheless, the comparison of this graph with the American is extremely interesting. It is significant to note the relatively higher repair rate which is usual with the four-cycle full Diesel engine, and that the British overall operating cost is low because the unit labor item is 40 per cent. of the American. The unit fuel and lubricating oil cost is higher than the Ameri-

can because of the relatively higher cost of oil in Europe, in spite of the fact that the actual consumption should be lower because the British engines listed are all four-cycle, full Diesel, and the American are less efficient medium compression oil engines.

Figure 14 shows some further British operating data comparing steam and Diesel pumping plants and indicating a ratio of about 2 to 1 in favor of the Diesel.

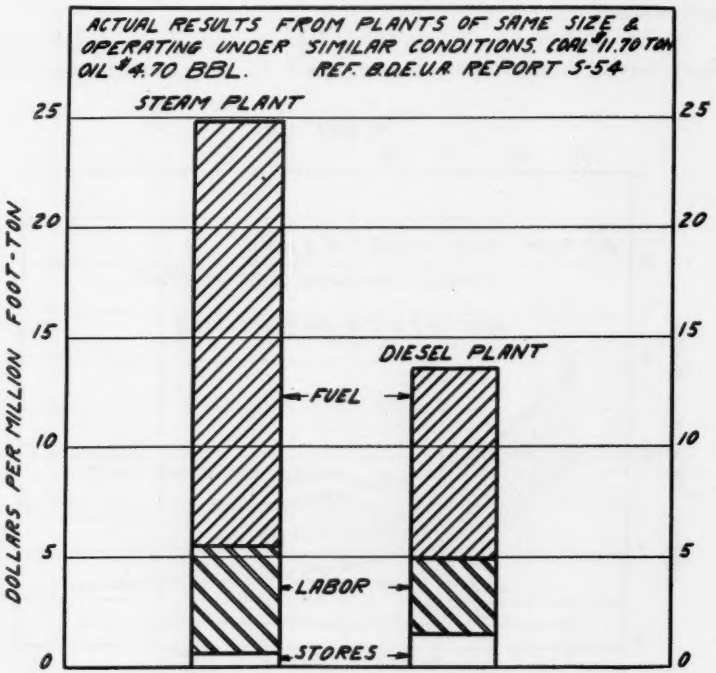

FIG. 14. — COMPARATIVE OPERATING COST OF STEAM AND DIESEL DRIVEN PUMPING PLANTS.

It was impossible to obtain actual American operating data on steam and oil engine pumping plants in comparable sizes, although Table 12 shows cost records for smaller plants. The operating costs for steam and motor-driven pumping plants were taken from public records in the office of the Railroad Commission for the State of Wisconsin at Madison. All of the plants are operating in municipal service, have about the same yearly load factor, and operate under the same general service conditions. It is rather interesting to note the costs of pumping with purchased power in a State where development of both steam and water power has reached a fairly high plane.

TABLE 12.

OPERATING COSTS OF THE OIL ENGINE PUMPING PLANTS OF TABLE 7 COMPARED WITH STEAM AND MOTOR DRIVEN PLANTS.
Note: Motor and steam plant costs from Railroad Commission, State of Wisconsin.

Plant.	No. of Pumps.	Gal. Pumped, Millions.	Static Head.	Operating Cost except Fuel and Lub. Oil.	Cost per Million Gal.	Fuel and lubricating Oil.	Fuel and lub. oil per Million Gal.	Total Operating Costs per Million Gal.	Fuel and Lub. Oil Cost corrected for 150 ft. head.	Total Operating Costs On Basis of 150 ft. head.	Price of Fuel Oil Coal, Current.
											c. per Gal.
5	2	142.	150	$1 805	$12.72	$1 505	$10.60	$23.32	$11.12	$23.84	11.9
10	1	163.3	322	2 115	12.92	1 532	9.38	22.30	4.37	17.29	6.47
15	2	87.6	402	1 260	14.38	619	7.07	21.45	2.64	17.02	4.0
16	1	222.	402	2 040	9.20	2 568	11.55	20.75	4.32	13.52	6.02
26	2	262.1	200	4 046	15.41	1 457	5.56	20.97	4.17	19.58	3.57
STEAM PUMPING PLANT COSTS.											
											$ per Ton.
Marinette	4	617.	150	$4 142	$6.70	$15 806	$25.60	$32.30	$25.60	$32.30	$6.72
La Crosse	8	1 213.	240	18 780	15.45	19 419	16.00	31.45	10.00	25.45	6.89
Berlin	2	77.4	135	4 066	52.70	2 093	27.10	79.80	30.50	83.20	7.00
Washburn	2	155.8	250	2 840	18.25	6 186	39.75	58.00	23.80	42.05	9.33
Janesville	4	589.	175	6 760	11.45	7 405	12.55	24.00	10.75	22.20	6.04
Kenosha	5	1 670.	162	17 491	10.45	19 816	11.85	22.30	10.97	21.42	7.60
So. Milwaukee	6	317.	210	11 536	36.50	11 847	37.40	73.90	26.70	63.20	7.60
MOTOR DRIVEN PUMPING PLANT COSTS.											
							Current Costs.				c. per Kw.-hr.
Menominee	2	170.	240	$3 361	$19.80	$5 633	$33.10	$52.90	$20.70	$40.50	1.25
Delavan	3	244.3	125	3 560	145.80	1 378	56.60	202.40	68.00	213.80	3.0
Columbus	2	466.5	135	767	16.50	1 573	34.80	51.30	38.70	55.20	3.5
Castleton	1	146.7	223	1 374	93.50	1 533	104.20	197.70	70.40	163.90	4.5
Neenah	3	177.	110	3 642	20.60	8 246	46.50	67.10	39.40	60.00	....
Wisc. Rapids	4	214.	195	2 619	12.20	5 034	23.50	35.70	18.05	30.25	2.44
Chippewa Falls	4	371.6	185	2 471	6.65	6 475	17.40	24.05	14.10	20.75	1.44
Lake Geneva	4	608.7	186	3 531	58.00	4 132	67.80	125.80	54.70	102.70	3.0
Stoughton	3	150.4	185	2 904	19.35	3 190	21.20	40.55	17.20	36.55	2.0
Waukesha	8	536.6	150	7 133	13.28	18 494	34.50	47.78	34.50	47.78	2.39

Table 13 lists some very significant data on the subject of reliability and certainly establishes the fact that the Diesel engine is a most reliable prime mover. Diesel engines are coming into general use as stand-by units in hydro-electric plants on account of the ability of the Diesel to start immediately. Such dependability is essential in pumping plants for fire service.

TABLE 13.

RELIABILITY AND DEPENDABILITY OF THE OIL ENGINE PLANTS IN TABLE 7.

Plant No.	Years Service.	No. Units.	Plant Shut Down due to Engines—hrs.	Number of Failures to Start Promptly.	Longest continuous Run of any Engine—hrs.
1	1½	2	...	..	90
2	8	3	...	..	144
3	1	2	3	..	1 350
4	2	1	1	2	16
5	3	1	...	..	18
6	1	2	...	..	85
7	6	2	1	..	21
8	5	3	1½	3	60
9	4	2	...	..	144
10	1½	1	...	..	144
11	10	1	321	..	2 324
12	4	1	...	..	366
13	4	2	...	..	656
14	8	2	...	..	1 440
15	4	2	...	..	18
16	1½	1	...	..	18
17	10	3	...	..	18
18	3	1	...	..	16
19	2	4	10 min.	..	48
20	1	3	15 min.	..	48
21	1	1	...	..	492
22	6	2	...	..	24
23	6	2	...	..	164
24	1	2	...	..	120
25	1	2	20 min.	..	2 160
26	4	2	...	..	528
27	4	3	...	..	3 360
28	2	2	48 min.	..	1 176
29	3	1	...	..	216

Assuming the same total operating costs and labor costs, Fig. 15 shows necessary current cost for motor drive as compared to oil-engine cost from actual operating data discussed previously. With fuel at 5 cents per gallon and lubricating oil at 55 cents per gallon, current would have to be sold at less than 1 cent per kw.-hr., so that total yearly costs would be equal for the oil engine and electric driven plants. This substantiates through actual operating records Maury & Gordon's report of estimated total cost analysis.

Operating records are often unfair on account of average low running load factor and high peaks, necessitating large total plant capacity. Figure 16 shows the great benefit of using multiple units in Diesel engine plants to

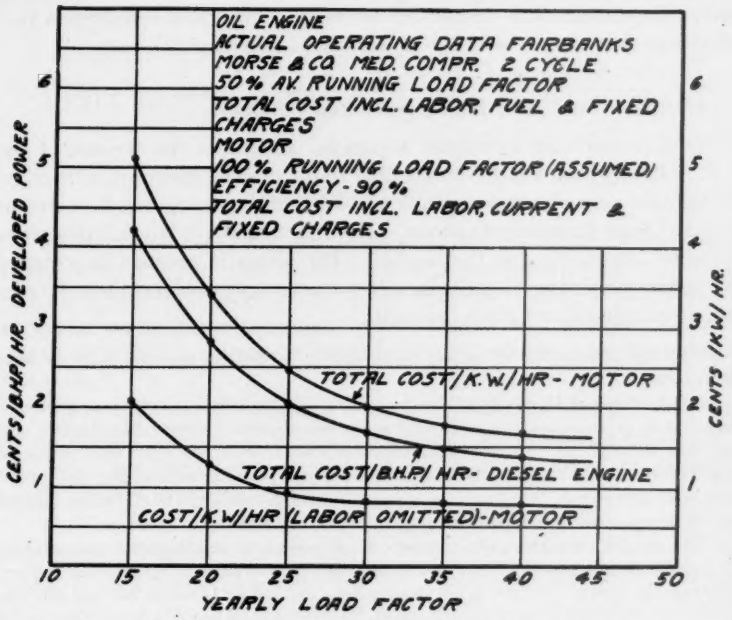
OIL ENGINE
ACTUAL OPERATING DATA FAIRBANKS MORSE & CO. MED. COMPR. 2 CYCLE
50% AV. RUNNING LOAD FACTOR
TOTAL COST INCL. LABOR, FUEL & FIXED CHARGES
MOTOR
100% RUNNING LOAD FACTOR (ASSUMED)
EFFICIENCY - 90%
TOTAL COST INCL. LABOR, CURRENT & FIXED CHARGES
TOTAL COST/K.W./HR - MOTOR
TOTAL COST/B.H.P./HR - DIESEL ENGINE
COST/K.W./HR (LABOR OMITTED)-MOTOR
CENTS/B.H.P./HR. DEVELOPED POWER
CENTS/K.W./HR.
YEARLY LOAD FACTOR
10 15 20 25 30 35 40 45 50
1 2 3 4 5 6

FIG. 15. COST PER KW.-HR. FOR MOTOR DRIVE TO EQUAL OIL ENGINE DRIVE.

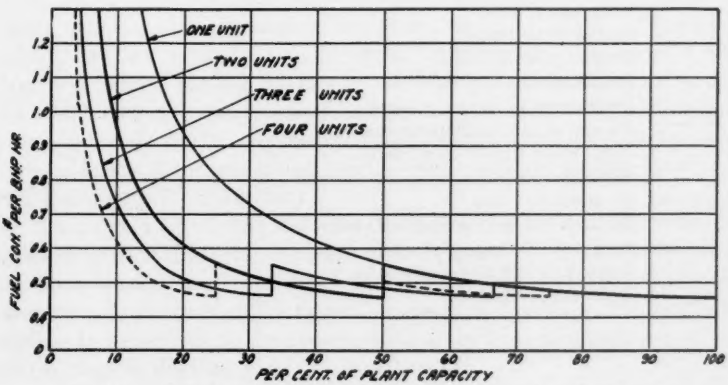
ONE UNIT
TWO UNITS
THREE UNITS
FOUR UNITS
FUEL CONS. PER B.H.P. HR.
PER CENT. OF PLANT CAPACITY
0 10 20 30 40 50 60 70 80 90 100
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.1 1.2

FIG. 16. — COMPARISON OF FUEL CONSUMPTION WITH MULTIPLE UNITS.

efficiently meet such conditions and make possible the lowest unit operating costs. This condition is distinctive of Diesel engines and comprises a just advantage over steam, inclusive of the largest size plants.

U. S. Shipping Board Program.

It is proper that we should discuss for a moment the decision of the U. S. Shipping Board in recommending that Congress appropriate twenty-five million dollars for the conversion of some of the emergency fleet steamships to Diesel Engine motorships. The shipping board studied this problem most intensively and thoroughly. The points of greatest importance stressed in the Congressional committee's hearings to substantiate the wisdom of conversion are given herewith:

1. Of the new ships of all nations being built at the present time, 60 to 70 per cent. are motorships.

2. Experience with the American Motorship *William Penn* (12 000 ton) showed a consumption of ½ the quantity of fuel oil as the same size and speed oil-fired steam turbine ship, 40 to 50 per cent. less operating labor costs than steam, 6 per cent. increased cargo carrying space than steamer, two weeks per year saved in overhauling and repairs as compared to steam. On four trips around the world, totalling 110 000 miles, elapsed time 27 months, the total repairs amounted to less than $200.

The greater cleanliness and comfort of a Diesel plant and the better pay afforded the smaller crew tends to attract and retain higher grade men to operate the engines. Whereas, the cost of conversion per dead weight ton will be between $50 and $60, the savings in cost of operation alone will absorb the total investment in a period of from five to six years, not taking into account the greater potential earning power of the converted vessels. Admiral Benson testified that the whole marine world was going into Diesel engines and that the steam engine is a thing of the past in commercial operation.

In summing up, it is only proper to list the general advantages of Diesel engines over other types of prime movers:

1. Economy.
2. Long, useful life.
3. Simplicity in design.
4. Simplicity in operation.
5. Small floor space.
6. No chimney — smoke — ashes.
7. No coal or ash handling apparatus.
8. Large water supply unnecessary.
9. Small operating force.
10. No stand-by losses.
11. Instantly ready to deliver full power.
12. No service or demand charges.
13. Low repair and maintenance.
14. Best overall efficiency.

DIESEL ENGINE EXPERIENCE IN A PUMPING PLANT.

BY LEONARD C. L. SMITH.*

[*Read March 10, 1925.*]

Mr. President and guests, and members of the New England Water Works Association: Will you pardon me if I express my appreciation of being in your midst this afternoon, as the names of so many of your members are household words in my community and in my home; and their works, I confess with deep humility, are more familiar to me than the Westminster Catechism.

I have been particularly interested in Mr. Jahnke's paper. Much of the information contained in it I have heard this afternoon for the first time, and I am particularly gratified to find that the plant I am about to describe stands so well in efficiency.

The few facts that I have to present, and the short time required for their presentation, do not need a paper and scarcely justify the use of the word; but I trust you will not consider that the measure of their importance, for they form a part of a record which, to my mind, constitutes a distinct advance in the economics of the small pumping station. All I have to say can be written on an ordinary three-by-five index card, but I hope that such a card may be found worthy of a place in your files.

In this connection, I am reminded of the story of the farmer who came down to the country store one evening looking very worn and weary, and being chided about his condition by his colleagues, who had already gathered within expectoration distance of the stove, he said, "Well, I have got a right to be; do you know that old wood lot of mine? It is about a mile long, and today I plowed 100 furrows through it." A flippant young person said, "Well, you don't mean to tell us that you walked 100 miles behind a plow today, do you?" He fixed the young man with an icy stare and said, "Young fellow, I am just giving you the facts; you will have to draw your own conclusions." (*Laughter.*)

I am reminded of that story for the reason that when I first drew my conclusions from the facts connected with the plant which I am to describe, they were so surprising to me that I went back and checked them and looked carefully over the data. The facts I am ready to vouch for; but, not to be outdone in generosity by the farmer, I am going to accord each one of you the privilege of drawing your own conclusions.

So, first, as to the facts: The Huntington Water Works Company supplies practically all of the unincorporated village of Huntington, Long

* Consulting Engineer, Long Island City, New York.

Island, which for many years has nestled among the hills of Suffolk County, New York, but which of late years has filled the valleys with beautiful homes and crowned the hills with millionaires' mansions; and the Company has had to meet the ever-increasing problems of additional demand and greater pressure for its service.

The village now has a two-service system, the high service corresponding to a pressure of 175 lbs. in the pumping station, and the low pressure service 143 lbs. in the pumping station, giving an average lift for last year — almost exactly half of the water going to the high pressure and half going to the low service — of 386 ft.

The supply being so short in 1923, the speaker was called in and asked to give them recommendations, and it was very shortly decided that the old site would not give an adequate additional supply, and a new site was obtained some four thousand feet farther north than the old site.

It was also recommended that the steam plant then in existence be left intact and used as an auxiliary, and only one unit be put in the new station. After some consideration, as comparisons are odious, it will suffice for me to say it was decided to put in a type Y, Fairbanks-Morse, four-cylinder engine, rated at 200 h.p., direct connected to a Gould horizontal duplex pump, and they were purchased under a contract with Fairbanks-Morse & Company in order to avoid any division of responsibility as to the engine and pump installation. The pipe was put in by day labor by the Huntington Water Works Company, the foundations under a contract with one of the local men, and the building under a contract with another local man.

The station building cost $14 500, the engine and pump $23 000, the foundations $996, and the piping about $2 000, making a total of $40 496. This of course does not include the cost of the site or the cost of the well.

The plant was completed in February, 1924, but owing to difficulties with the suction line and with some of the wells, which were constructed under very wet conditions, we had no continuous operation of the plant until the latter part of March of last year, so that the record which I give you is from the first of April, 1924, to the 31st of January, 1925 — a period of ten months. During that time we used 16 607 gal. of fuel oil which cost us, in the tank at the station, seven cents — a rather high rate, owing to the fact that we are some two miles from the station and it has to be delivered in tank wagons. We also purchased other fuel and supplies amounting to $166, so that the total cost of fuel and supplies for the ten months amounted to $1 329.16.

We pumped during that ten months 113 145 000 gal., and a very simple problem in arithmetic will demonstrate that the fuel supply cost per million gal., against a total head of 386 ft., was $11.77. The station man's wages for the same period was $1 820; and you will please bear in mind that it would be the same had the station produced six times as much water as it did. This made the labor cost rather high. It was $16.10 per million

gal. delivered from the station. That made a total for the delivery with supplies, fuel, and wages of $27.87. Those are the facts.

I concluded — and you may dispute the rest of my conclusions if you will — that 3.4 per cent of the total investment would be sufficient for the annual charge, inasmuch as I had charged high depreciation; not having the same faith in the Diesel engine that Mr. Jahnke has, I assumed 10 per cent. depreciation for the engine and 2 per cent. for the buildings.

Without insurance it made a total cost for overhead of $3 319.85, equivalent to $29.37 per million gal. So that the total cost of the water put out of the station per million gal., against a head of 386 ft., was $57.24.

The principal competition that we had when we built the station was from the local electric light company, which offered us current at three cents per kw.-hr., so that for purposes of comparison I have just figured the number of kw.-hr. work we have done during the ten months. It amounted to 137 026, which, with a fuel cost of $1 329.16, gives a little less than one cent per kw.-hr. And please remember that this is based on work that is turned out of the station, whereas if we bought the power at the switchboard or behind it we would have the switchboard losses, the losses in the motors, and losses in the engine, and would have had to purchase at least 25 or 30 per cent. more current than I have given you as the output of the station.

I am trying, gentlemen, only to give you the salient facts and not to burden the record with a lot of irrelevant material, and have no intention of withholding any information that any of you would like to have.

May I add one fact that slipped my mind. We did not present any curve to the Board of Directors in connection with this plant, but we did show them the fuel bill for 1923, which amounted to a little over $10 000, and the fuel bill for 1924 which amounted to less than $1 500, although we pumped some 30 000 000 gal. more in 1925 than we did in 1924.

Permit me, in conclusion, to thank you for the courtesy of your invitation to present these facts and for your kind attention.

DIESEL ENGINE EXPERIENCE IN A MODERN FORGE PLANT.

BY J. P. HARBESON, JR.*

[*Read, March 10, 1925.*]

In presenting this paper to the members and friends of the NewEngland Water Works Association, it is my object, not to set up theories or arguments in favor of, or detrimental to, the Diesel Engine, but merely to cite facts and figures that have occurred and are occurring in the operation of two Diesel Engine Generator Sets under my supervision; together with the reasons for adopting this source of power, the troubles encountered and how overcome, and the results obtained.

It seems that present-day America is basing all periods of time on the World War, therefore, to be in line: During the stress times when the Camden Forge Company was working on a twenty-four hour day, seven days per week schedule, producing forgings for war use, and every mail brought more insistent demands for increased shipments, we found that the neck of the bottle was the power plant. On looking into the matter, we found that our source of power had to be increased 300 to 400% and that in a very great hurry. Buying steam prime movers, either straight-line or turbine, was out of the question, owing to the length of time for delivery on both engines and boilers; therefore our only salvation was to install conversion units and purchase our power.

This was done, the units bought being synchronous motor generator sets taking purchased current at 2 300 volts, 2 phase, 60 cycle, and delivering it at 230 volts direct current — the conversion loss being approximately 5%. The conversion was necessary to fit the existing motor equipment throughout the plant.

As is probably universal with Public Utility companies selling commercial power, the selling price was based on the maximum demand in horse power; this figure was a constant, and was increased by the actual consumption in kw.-hr., priced on a sliding scale dependent on the amount used; then this increased figure was further augumented by a surcharge of 25% of the two foregoing and an additional amount was added as a coal charge dependent upon the price of coal at the power station. From this total was allowed a 5% discount for paying the power bills within ten days after presentation. The result of these charges was an average cost to us during our connection of $.0273 per kw.-hr. The lowest cost was $.0183 per kw.-hr. when the consumption was 288 000 kw.-hr. and the highest was $.1033 per kw.-hr. when the consumption was 1 500 kw.-hr.

* Chief Engineer, Camden Forge Co., Camden, N. J.

These costs are direct charges and do not include depreciation or repairs on the conversion units or their switchboards, nor interest on the capital investment necessary for their purchase. Then again, if no current was used there was a "standby charge" amounting to 50% of the maximum demand.

These figures will conclusively show that purchased power was rather expensive and prompted us to cut loose from it as soon as possible. This, together with the feeling of greater security in having our total power production under our own hands, directed us toward the Diesel Engine. I will not deny that steam was also considered, but lack of additional boiler space and the excessive costs of both boilers and engines argued again for Diesel Engine power. We investigated and were gratified with the results being obtained by the plants using this type of power. Furthermore, being in the forge business and buying oil in large quantities for heating furnaces, we were not forced to increase our investment by the purchase of storage tanks, oil pumps, etc.

We therefore placed our order for 2 Diesel Engine Generator Sets of the following characteristics:

Six cylinder, 2 cycle, low compression type, 300 brake h.p. at 257 r.p.m., direct connected to 200 kw. — 230 Direct Current Generators. The engines selected were built by the Fairbanks-Morse Company of Beloit, Wis., and known as their "Y" type, the generators being furnished by the Crocker-Wheeler Co. of Ampere, N. J.

The principal reasons for these selections were: simplicity of design, few outside moving parts, an engine shipped as a whole (lessening the erection time), and the low cost per h.p. Respecting the generators, these were selected to match the generator end of three automatic high-speed steam-engine generator sets already installed. These five are all synchronized and deliver their power to a distribution board.

The Diesel units were started, the first in June, 1923, and the second in December of the same year. A test was run on both units separately after the installation of the second one, with the following results:

Cost of power at the switchboard — direct charges only	$.0095 per kw.-hr.
Cost of power at the switchboard — direct and indirect charges	.0189 per kw.-hr.
Fuel consumption per kw.-hr.	.1385 gal., or 1.036 lbs.
Duration of tests	11 hr.
Average voltage	250

In the first figure of $.0095 per kw.-hr. the individual costs include

Fuel oil for operating at 4½c. per gal. delivered engine storage tanks
Lubricating oil
Kerosene for heating the starting torches
Gasoline for operating the air compressor for starting
Water, and
Labor

In the labor charge two men are considered, — the power house engineer, whose time is distributed over all the equipment in both the engine and boiler rooms, and an oiler whose time is distributed over the operation of the engine-room equipment only.

The direct and indirect charges of $.0189 per kw.-hr. also include interest at 6% on the total investment, including engine, generator, air compressor, and foundations; depreciation of 10% per annum on the cost of the equipment only, and repairs (which figure was an approximation assumed at $2.00 per day and since proven to be more than ample).

The direct and indirect charges were separated to show a more exact comparison between the cost of Diesel Engine produced power and Public Utility high-tension power, converted; inasmuch as the direct charges of the Diesel Engine produced are comparable to the billed charges of the purchased; the indirect charges applying in both cases, varying slightly with the cost of the equipment in each instance. In other words, the $.0095 is comparable to the $.0273 mentioned in connection with the power above.

Those of you who are familiar with the operations in a large forge plant will appreciate the very varying requirements in the way of power. The only constant load is that occasioned by the furnace blowers and lights, amounting to about one-quarter of the total; the balance is made up of machine tools and cranes, some of the latter having 50 and 100 h.p. motors. The ammeters on the distribution board will vary from $\frac{1}{2}$ to $1\frac{1}{4}$ full load momentarily. The fact is mentioned merely to show the necessity of flexible prime movers in forge shop work and the Diesel engines respond quickly and quietly to this variation in load.

A little difficulty was occasioned shortly after starting the first engine, due to carbon blocking the exhaust ports. This was investigated and found to be due to the fuel oil then being used. Going into the matter we found that fuel oil is made by two different basic methods; one in which the fuel oil is called a distillate, actually produced by distillation; the other called residuum base fuel oil, being produced by cutting back low Be′ fuel oils with the light hydro-carbons. This latter fuel oil (while in itself light 26 to 30 Be′) therefore carries great quantities of suspended undissolved particles which were the principal causes for our difficulty. This was simply taken care of by segregating one of the fuel oil tanks for distillate oil for the engines, with a separate line to the power house. This was our only serious trouble, which has been easily overcome, the accumulation of carbon now amounting to about a cupful per engine per week.

DIESEL ENGINES — DISCUSSION.

SAMUEL A. AGNEW.* I would like to ask the Fairbanks-Morse representatives why they are advocating the two-cycle engine. One of their men has been to see me and he assures me that all the world is going to use them. I have operated four-cycle engines of the old type and I have found them very, very satisfactory, but the gentleman from Fairbanks-Morse & Company comes and assures me that two-cycle engines are far superior to the old four-cycle. I was rather skeptical at the time, and I would like, if it is possible, to have them tell us just what the superiority of the two-cycle engine is over the old four-cycle engine.

MR. JAHNKE. The most important point in favor of the two-cycle engine, as compared with the four-cycle, is the greater simplicity of the engine as a machine. Where you have less moving parts — less mechanism, — you naturally have less trouble.

I do not know whether you noticed, as we flashed on the screen the records of the Diesel engine users of England, as compared with those in America, that the Diesel engine records from England were on the four-cycle engines, and the cost of repairs was about six times what it was on the two-cycle engines. That is one of the most important items in favor of the two-cycle engine.

Another important item, I believe, in favor of the two-cycle engine, is the fact that, as a rule, you can employ cheaper labor; it does not require such a good mechanic to maintain good engine operation. I showed you that the average salary per year of oil-engine operators in the Fairbanks-Morse & Company installations is at the rate of $1 500 a year, which means about $125 a month. This is a relatively low rate of pay for a good mechanic of today, and I think it is a proven fact that it does not take as good a mechanic to operate a simple machine as it does one that is more complicated.

Now, the four-cycle engine is an economical engine — I do not think that in any of our discussions we have tried to suggest that it was not; but we have always favored the two-cycle engine primarily on account of its great simplicity and the fact that we felt, from our development work, that ultimately the two-cycle engine would show the same fuel economy and much higher overall efficiency than the four-cycle engine. I think it is actually doing that today.

You will notice that most of the engines which are being sold to the Shipping Board, and which are prime movers of 2 000 or 3 000 h.p., are two-cycle engines. And it seems today that most of the manufacturers who are in the oil-engine business are drifting towards the two-cycle design on

* Superintendent, Water Works, Hingham, Mass.

account of its greater possibilities, both from the manufacturing standpoint and the users' standpoint. Does that answer your question at all? You probably do not agree with me. You have had experience with the four-cycle engine and you are a satisfied user. There is no better endorsement of the oil engine than to have a man get up and say he is using a four-cycle Diesel engine and is satisfied. We are satisfied in having that statement. We really believe that if you had a two-cycle engine you would be just as well satisfied, and if you were in the market today for an engine, you would probably buy a two-cycle engine. There is less mechanism to it, and generally the price is less.

LEONARD METCALF.* Mr. President, I have listened with a great deal of interest to these three admirable papers. They are a very distinct contribution to the literature on the subject.

We have recently had to do with a plant in the Middle West in which there is a water consumption of about fifteen million gallons a day, in which we had occasion to study the different types of machines which could be used to advantage. The thing which interested me particularly, was that we found we could not consider the motor-driven machinery unless we had a current rate of about one cent per kw.-hr. At one cent per kw.-hr. we found that we could pump our water more cheaply by steam power than by electric power; but when we finally got a rate of 0.9 of a cent per kw.-hr., the advantage seemed to be with the motor-driven machinery.

There is one point that was raised by Mr. Jahnke on which we differed somewhat from his point of view, and that was as to the number of men required per shift. It did not seem to us that in a public water supply, supplying as much water as I stated, it would be wise to limit the number of employees on a shift to one man. Should anything go wrong with this man, the station would be without an attendant. This appeared to be too serious a risk to be taken. Therefore, when we figured on the cost of the motor-driven machinery we required that we should have at least two men on a shift, purely as a factor of safety in the operation of the station and the maintaining of desirable service.

It has been very interesting to me to see, as time has passed, the greater reliability and confidence that has come, and come very naturally, in the Diesel engine. I remember some years ago — I think, perhaps, ten or fifteen years ago — we made a report for the San Antonio Water Supply Company, recommending the installation of additional pumping machinery there. There was a large Belgian interest in the company at that time, which had a consulting engineer in Belgium to whom our report was sent, and it was his suggestion that we substitute the Diesel engine for the type that we had proposed. At that time the experience had not been altogether advantageous to the Diesel engine, in the remoter districts at least, and we felt that at that distance from large centers of population and industry, we were not so confident of continuous service from the Diesel

* Of Metcalf & Eddy, Consulting Engineers, Boston, Mass.

engine, as this engineer had been able to realize in Belgium, where the engine had been perfected and where he had men who were thoroughly familiar with that type of engine. Of course, with greater experience and additional installations, there are more men who do know how to run the engine; and with the greater simplicity of the mechanism to which Mr. Jahnke has repeatedly referred, I think there is general recognition of the greater reliability of the engine. Having more men, trained to that sort of machine, to draw upon, it makes it safe to make an installation where otherwise it might not be desirable. In the particular case cited, the Belgian engineer agreed finally that it was wise not to install the Diesel engine at that time. I think today the decision would be otherwise, probably.

PRESIDENT TAYLOR. I think Mr. Metcalf's point is well taken, — that in any thing as important as a public water supply we can not afford to depend upon only one operator in a plant. We discussed that question at home, and my chief engineer and I have agreed that it is too serious a matter to leave a pumping station in the hands of one man who might have an accident or be suddenly taken away.

J. D. HARPER.* I do not think Mr. Jahnke is advocating the use of one man. The point he was trying to make was that it did not require more men to operate a Diesel-engine plant than it would require to operate a motor-driven plant; that you had to have one man in the smallest plant, and up to a certain size, one man would take care of it whether it were a motor-driven plant or an oil-engine plant. I think really that was the point he was trying to make. And I agree with the last speaker that the question of safety would require two operators in any plant of any considerable consequence.

I do happen to know that in the State of Texas, where the San Antonio Water Works people did not in the early days put in an oil-engine plant, most of the municipalities have put in oil-engine plants since. There are several hundred of them in Texas. They are very successful and have very wonderful records. Water is scarce and is not very good, and coal is high and is very, very poor. So natural conditions forced the engineers to see what they could do to better themselves, and if you take a map of the United States showing oil-engine installations, plotted on a large scale, you will see that they have a violent case of smallpox in the Southwest and that the rash is not quite so prominent on the Northeastern States.

J. HOWARD HAYES.† I think it is still to be brought to the attention of the Association as to where the first oil engine was operated in this country.

MR. AGNEW. Norwalk, Connecticut.

MR. HAYES. I know where the second one is, and it has been running since 1898. It has been operated by Mr. Tower at Cohasset. He tells me he has had practically no repairs but it does need a new piston ring now.

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* Manager, Oil Engine Division, Fairbanks-Morse & Co.

† Of Hayes Pump and Machinery Company, Boston, Mass.

MR. AGNEW. The first oil engine in the United States was installed in Norwalk, Conn., and it is still in daily operation.

I may add this, regarding the durability of the oil engine, — that they are getting practically the same efficiency as the day the engine was installed.

COLOR AND OTHER PHENOMENA OF WATER FROM AN UNSTRIPPED RESERVOIR IN NEW ENGLAND.

BY CALEB MILLS SAVILLE.*

[*Read November 11, 1924.*]

Although the matter is often one of importance in water supply work, very little information is available on the subject of color of water phenomena in new reservoirs from which the soil has not been stripped prior to filling.

The following facts are presented regarding conditions in the Nepaug and other reservoirs of the Hartford (Conn.) water supply system, as a contribution, without argument and merely for the purpose of putting them on record, with the hope that they may be helpful to another charged with the solution of the reservoir problem.

There are seven reservoirs of the Hartford water supply system from which the following data have been collected, and for convenience in discussion they may be separated into two groups.

Group I comprises Reservoirs 1 to 6, inclusive, lying on the easterly slope of Talcott Mountain, so called, which is a low ridge of basalt, protruding through the triassic shale of the Connecticut Valley, on the west side of the river of the same name, and located about eight miles west of Hartford. With the exception of Reservoir 4, the watersheds contain almost no swampy area. The slopes are quick and covered mostly with second growth hardwood, with a considerable sprinkling of hemlock and pine. The entering streams are small, and during the summer months the beds are mostly dry. The character of the soil cover of the rock is disintegrated shale and glacial till, covered with humus, and small springs only are to be found, which often cease to flow during the drier months. From this it is apparent that the water in the reservoirs is almost entirely that stored during the period of heavy run-off.

The reservoirs were constructed by dams across the streams of the main valleys, Reservoirs 2 and 6 being formed by long side-hill embankments. The bottoms were cleared of timber and brush, but practically little or no attention was given to removing or covering soil or small deposits of muck, except in limited areas. The data here presented for Group I have been collected mostly from the four reservoirs listed below:

Designation Reservoir.	Put in Service.	Area Drainage Basin, Sq. Miles.	Area Water Surface, Acres.	Max. Depth, Feet.	Total Capacity, Mil. Gal.
No. 2	1868	1.40	44	41	284
No. 3	1875	0.47	25	36	146
No. 4	1880	3.95	154	21	657
No. 6	1896	2.84	145	28	809

*Manager and Chief Engineer, Hartford (Conn.) Water Department.

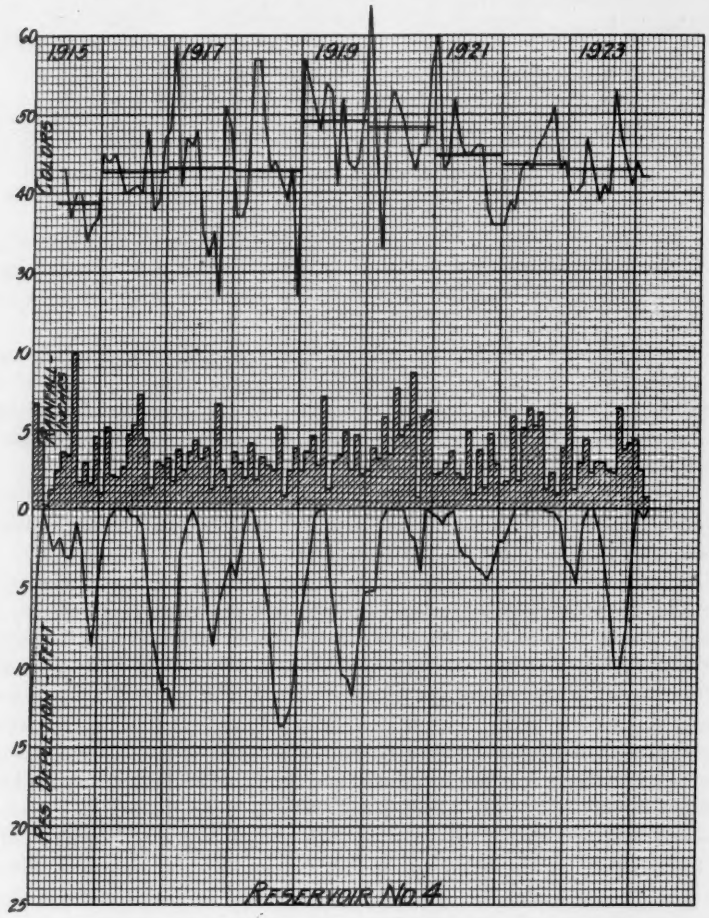


FIG. 1. — COLOR, RAINFALL AND RESERVOIR DEPLETION. RESERVOIR NO. 4.

The characteristics of Reservoir No. 4 are entirely different from those of the others; here the brook flowed through a rather broad and level valley, and later, in order to increase the tributary area, a low divide was cut through and about 2.1 square miles added. The greater part of this additional area was swampy, and while the additional quantity of water was not only out of proportion to that from other areas, but the quality was much inferior to that of other reservoirs, its color being so high at times as to cause it to be designated "Brandy Brook."

The average monthly colors, rainfall, and reservoir depletion for the nine years 1915–1923, inclusive, are shown on Fig. 1 and Fig. 2. In Table 1 is a comparision of the mean, maximum, and minimum colors by months for the nine years of record (1915–1923) for Reservoirs 2, 4, and 6.

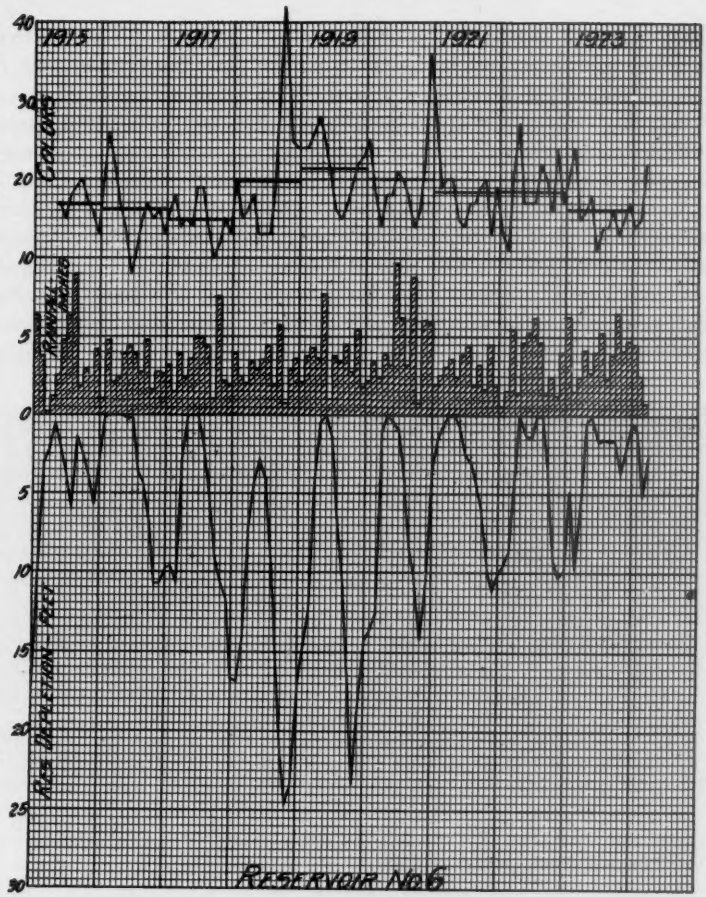


FIG. 2. — COLOR, RAINFALL AND RESERVOIR DEPLETION. RESERVOIR NO. 6.

TABLE 1.

MEAN COLORS.

Resv.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
No. 2	29.8	26.0	22.1	25.6	24.0	22.3	21.0	18.8	19.9	25.3	30.3	27.0
4	47.9	44.9	40.4	49.3	47.4	46.4	42.0	42.9	44.8	40.3	40.4	43.0
6	20.0	18.9	18.0	20.3	16.8	15.4	16.1	16.9	16.6	19.0	18.7	19.4

MAXIMUM COLORS.

No. 2	40	34	29	29	26	28	32	22	28	37	38	41
4	64	59	45	57	57	53	49	52	53	51	51	56
6	28	26	22	28	25	21	20	22	20	20	25	36

MINIMUM COLORS.

No. 2	22	29	14	23	20	10	13	13	14	15	19	18
4	36	37	33	43	40	39	35	32	35	27	36	27
6	13	11	14	15	13	8	11	14	10	12	13	13

The physical characteristics of Reservoirs 2 and 6 are so similar that some other conditions must be found to explain the differences in color of the stored water, as both of these reservoirs are now well within the limits of what may be considered old reservoirs, with their bottoms in stable condition. Such other conditions may be found in the storage capacity and in the area of water surface exposed to wind and sun action. While the drainage area of Reservoir 6 is about double that of No. 2, the area of water surface is four times, and its capacity is about 2.75 times that of No. 2. It is also probable that the difference in depth of the two reservoirs is a factor to be considered, that of No. 2 being about 46% more than No. 6, with consequent lessening effect of wind action upon total circulation of the water in the reservoir.

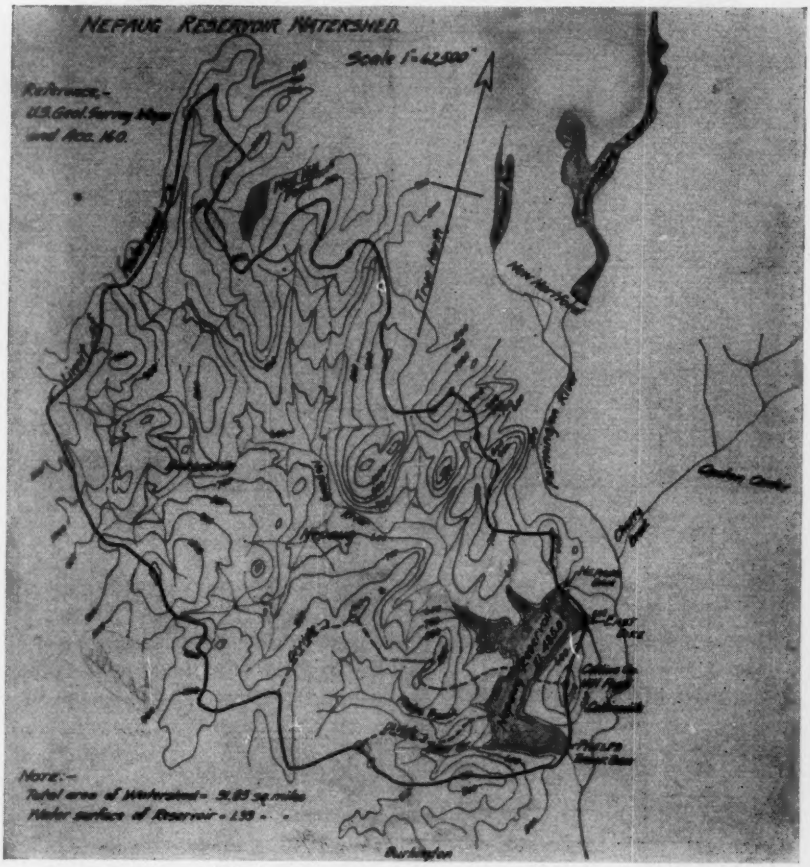


FIG. 3. — NEPAUG RESERVOIR WATERSHED.

Group II includes the Nepaug Reservoir (Fig. 3) and its 32 sq. miles of tributary watershed, which is located about 16 miles northwest of Hartford on a branch of the Farmington River, which it enters about a mile north of the village of Collinsville. The basin is roughly oval, with major and minor axes about 8.5 miles and 4.0 miles, respectively, the former lying about northwest and southeast.

The lower part of the basin is underlaid with Hartland schist, while the Becket gneiss is the country rock of the upper portion. The whole area was well worked over by the glaciers, as evidenced by the abundance of eskers, kanes and lacustrine deposits in the valleys and the exposed ledge outcrops in the higher portions. The surface topography is somewhat hilly, varying from an elevation of approximately 500 ft. to 1 000 ft. above sea level. The main Nepaug stream has an average fall of about 1 in 10. The surface of the basin is about equally divided between second growth forest and cultivated or pasture land. The swamp area is very small compared with the whole watershed area, and there are few deposits that might produce unfavorable color conditions. Due to extensive gravel and sand deposits, some of the small streams have a clear, low-colored water running nearly all of the time, and during periods of low run-off all of the streams are excellent in appearance, a small area only being most productive of high color.

The Nepaug Reservoir was formed by building dams across two streams, the Nepaug River and Phelps Brook. By this means, the surface of the ponded water was raised sufficiently high to top the low divide between the two streams, and thereafter a single pond resulted.

Previous to its filling, the basin contained 47 farms, the level bottom lands along the main stream being used for cultivation, while the steeper side slopes were mostly used for pasturage, with here and there patches of timber and second growth brush. The area was approximately divided into 343 acres of cultivated land, 168 acres timber land, 205 acres sprouts, 122 acres pasture, and 13 acres swamp.

In the construction of the reservoir all buildings were removed; all trees and brush were cut to ground level and the shores grubbed of all roots for 10 ft. below and 5 ft. above high water. Before final filling, the whole reservoir bottom was gone over with scythe and rake, all vegetable growth cut and burned, and the basin left in as clean and clear a condition as possible. One small area of peat deposit was noted, but was not treated. For the most part the reservoir bottom was underlaid with sand and gravel covered with a sandy subsoil underlying a rather thin topsoil, bare where formerly cultivated, and grass-grown elsewhere.

The total capacity of the reservoir is 9 500 million gal., its average depth 34 ft., with a maximum depth of 97 ft. near the Nepaug dam. There are few areas of shallow flowage, the largest single space being at the north end, where there are about 10 acres, with a maximum depth of 6 ft. Over this area the soil was stripped off to the gravel.

Four principal streams enter the reservoir: Clear Brook, a small tributary, comes almost entirely over open sand-bank country; Phelps Brook, with a somewhat larger tributary area, drains a mixed country, the lower portion steep and rocky, with forest cover, the upper part with much open farm land and some swamps; the Nepaug River, the main stream, drains

TABLE 2.

NEPAUG RIVER — RAINFALL, RUN-OFF AND COLOR. DRAINAGE AREA = 23.9 SQ. MI.

Month.	1917.			1918.			1919.			1920.		
	Rainfall Inches.	Run-off Sec. ft. per Sq. Mi.	Color	Rainfall Inches.	Run-off Sec. ft. per Sq. Mi.	Color	Rainfall Inches.	Run-off Sec. ft. per Sq. Mi.	Color	Rainfall Inches.	Run-off Sec. ft. per Sq. Mi.	Color
Jan.....	3.66	1.96	30	4.04	0.80	26	2.82	2.07	23	2.68	0.68	12
Feb.....	2.44	0.65	18	2.93	2.90	32	3.20	1.23	23	4.93	1.38	18
Mar.....	3.78	4.98	28	2.76	4.08	29	7.16	4.79	24	5.25	7.29	26
Apr.....	2.52	3.17	26	3.83	2.68	37	3.13	3.40	33	3.62	4.94	25
May.....	3.56	1.98	39	6.03	2.45	45	7.13	3.74	51	3.54	2.59	35
June.....	6.18	2.73	42	2.91	1.05	49	2.15	0.86	32	5.82	2.44	38
July.....	2.84	0.53	41	4.87	0.54	26	3.69	0.61	31	5.17	1.73	40
Aug.....	5.51	0.69	32	2.31	0.43	36	3.94	0.49	33	4.13	0.81	47
Sept.....	0.55	0.29	31	7.80	0.81	—	5.65	1.06	36	7.98	0.83	33
Oct.....	7.98	2.49	48	1.44	0.67	—	2.80	0.76	42	0.80	1.55	38
Nov.....	0.97	1.55	27	2.74	1.09	30	5.36	2.14	40	4.23	2.01	43
Dec.....	3.05	1.10	22	3.50	1.93	20	2.55	1.94	28	5.38	3.60	34
Year...	43.04	1.86	32	45.16	1.62	33	49.58	1.93	33	53.53	2.48	32

Month.	1921.			1922.			1923.			1924.		
Jan.....	2.79	2.09	20	1.47	0.45	22	8.77	2.46	30	4.92	3.48	22
Feb.....	2.70	1.46	29	2.13	1.03	30	1.79	1.15	27	2.10	0.85	22
Mar.....	3.12	4.49	29	4.04	3.92	32	2.87	5.03	27	0.93	1.72	23
Apr.....	5.88	3.61	31	2.60	3.45	32	4.31	4.61	30	7.27	5.53	27
May.....	2.55	1.89	34	6.32	2.84	33	2.90	2.35	31	4.35	3.23	33
June.....	3.81	0.73	28	5.18	1.25	40	3.64	1.00	30	2.47	1.24	26
July.....	3.81	1.14	42	4.43	0.92	44	1.66	0.30	32	1.41	0.28	24
Aug.....	2.76	0.41	31	5.99	0.90	37	2.84	0.26	27	4.34	0.35	30
Sept.....	4.45	0.30	30	2.07	0.70	36	2.32	0.36	30	6.18	0.52	29
Oct.....	1.57	0.38	32	5.00	1.19	45	6.32	1.23	27	0.14	0.52	25
Nov.....	5.10	1.04	34	1.31	0.73	33	2.77	1.02	28	3.39	0.62	25
Dec.....	2.16	1.26	35	3.92	0.60	28	4.01	2.55	30	2.11	0.88	24
Year...	40.70	1.57	31	44.46	1.50	34	44.20	1.87	29	39.61	1.60	26

about three-quarters of the whole basin, which is ordinary New England country area, — pasturage, open farm land and forest growth, and some bare rocky and sandy areas, but little swamp land that would be detrimental to the run-off; the fourth is the Collinsville Reservoir stream, draining about 0.4 sq. mile, swampy at its lower end but heavily timbered on steep rock or gravel slopes in its upper portion.

The color characteristics of the Nepaug Reservoir and its streams have been carefully observed since work first began. The study began in 1912 with the streams running in their natural channels prior to the beginning of construction work, and has been continued to the completed and seasoned reservoir in 1924. (See Tables 2 to 5, inclusive.)

TABLE 3.

PHELPS BROOK — RAINFALL, RUN-OFF AND COLOR. DRAINAGE AREA = 2.9 SQ. MI.

Month.	1917.			1918.			1919.			1920.		
	Rainfall Inches.	Run-off Sec. ft. per Sq. Mi.	Color	Rainfall Inches.	Run-off Sec. ft. per Sq. Mi.	Color	Rainfall Inches.	Run-off Sec. ft. per Sq. Mi.	Color	Rainfall Inches.	Run-off Sec. ft. per Sq. Mi.	Color
Jan.	3.66	1.38	37	4.04	0.72	42	2.13	1.37	31	3.81	0.46	23
Feb.	2.44	1.04	29	2.93	2.07	37	3.23	0.92	29	5.09	0.64	24
Mar.	3.78	3.54	36	2.76	4.79	37	6.11	4.37	32	4.34	6.85	39
Apr.	2.52	2.49	35	3.86	2.33	51	3.36	2.88	51	5.72	5.08	41
May	3.56	1.93	41	3.83	1.79	69	8.33	3.99	75	3.62	3.09	44
June	6.18	1.99	62	3.15	0.60	44	1.62	0.77	50	8.85	2.73	49
July	2.84	0.89	54	4.48	0.26	33	4.01	0.42	46	4.61	1.89	69
Aug.	5.51	0.56	39	3.24	0.18	38	4.70	0.27	43	1.89	0.55	60
Sept.	0.55	0.24	26	5.72	0.61	—	5.64	0.87	48	7.70	0.70	42
Oct.	7.98	1.79	63	0.67	0.21	—	3.27	1.03	58	0.64	0.97	45
Nov.	0.97	1.13	42	3.03	0.74	62	4.88	1.82	39	6.63	1.87	48
Dec.	3.05	1.20	25	3.57	1.16	37	2.94	1.46	36	4.46	2.97	45
Year	43.04	1.52	41	41.28	1.29	44	50.22	1.68	45	57.36	2.32	44

Month.	1921.			1922.			1923.			1924.		
Jan.	3.34	1.85	29	1.46	0.44	20	7.07	2.99	29	5.24	2.50	34
Feb.	3.86	1.59	21	2.51	1.75	31	1.81	1.39	30	2.57	0.66	25
Mar.	3.44	4.39	37	6.08	3.43	35	3.30	5.30	30	1.34	2.36	25
Apr.	6.64	3.65	41	1.66	2.95	44	5.95	5.61	36	9.16	6.70	40
May	3.20	1.98	47	5.95	2.60	45	2.72	2.67	43	4.96	3.74	49
June	3.35	0.54	37	5.44	1.58	49	3.91	1.44	40	3.22	1.61	40
July	4.23	0.90	47	4.62	1.80	58	2.00	0.39	40	0.98	0.27	28
Aug.	2.38	0.51	35	5.81	1.41	53	2.28	0.16	36	4.58	0.31	31
Sept.	4.47	0.36	29	2.24	1.04	50	2.84	0.20	29	5.63	0.62	32
Oct.	1.98	0.40	41	5.84	1.66	42	6.13	1.04	37	0.14	0.48	30
Nov.	5.81	1.32	47	1.34	0.89	38	4.12	0.97	30	3.71	0.59	29
Dec.	2.35	1.76	37	3.72	0.68	35	4.18	1.80	35	2.16	0.64	28
Year	45.05	1.60	37	46.67	1.69	42	46.31	2.01	35	43.69	1.71	33

In 1912 the average color of the Nepaug River was 31, with a maximum color of 82; in 1913 the colors were, respectively, 27 and 58. For Phelps Brook the average color observed in 1915 was 48, with a maximum of 83. Since 1917 both color and run-off observations usually have been taken weekly at many regular stations in the reservoir and on the principal tributary streams.

TABLE 4.

CLEAR BROOK — RAINFALL, RUN-OFF AND COLOR. DRAINAGE AREA = 1.05 SQ. MI.

Month.	1917.			1918.			1919.			1920.		
	Rainfall Inches.	Run-off Sec. ft. per Sq. Mi.	Color	Rainfall Inches.	Run-off Sec. ft. per Sq. Mi.	Color	Rainfall Inches.	Run-off Sec. ft. per Sq. Mi.	Color	Rainfall Inches.	Run-off Sec. ft. per Sq. Mi.	Color
Jan.	3.66	1.44	—	4.04	1.50	10	2.13	1.39	12	3.81	1.12	10
Feb.	2.44	1.35	—	2.93	1.80	10	3.23	1.37	18	5.09	1.50	12
Mar.	3.78	1.94	—	2.76	2.27	22	6.11	2.25	16	4.34	2.73	19
Apr.	2.52	2.14	—	3.86	2.25	10	3.36	2.51	16	5.72	2.76	19
May	3.56	2.01	—	3.83	2.16	12	8.33	2.88	19	3.62	2.74	13
June	6.18	2.18	—	3.15	1.71	12	1.62	2.05	16	8.85	2.84	15
July	2.84	1.92	—	4.48	1.59	13	4.01	2.10	18	4.61	2.10	11
Aug.	5.51	1.72	—	3.24	1.29	24	4.70	1.84	17	1.89	1.48	13
Sept.	0.55	1.36	—	5.72	1.31	—	5.64	1.82	26	7.70	1.55	13
Oct.	7.98	1.64	—	0.67	1.23	15	3.27	1.78	21	0.64	1.43	16
Nov.	0.97	1.47	—	3.03	1.20	19	4.88	1.96	13	6.63	1.60	24
Dec.	3.05	1.38	16	3.57	1.30	12	2.94	1.37	13	4.46	1.96	21
Year	43.04	1.71	—	41.28	1.63	14	50.22	1.94	17	57.36	1.98	16

Month.	1921.			1922.			1923.			1924.		
Jan.	3.34	1.61	12	1.46	0.95	8	7.07	1.67	10	5.24	1.87	12
Feb.	3.86	1.83	12	2.51	1.12	12	1.81	1.68	—	2.57	1.36	11
Mar.	3.44	2.54	16	6.08	1.52	21	3.30	2.75	14	1.34	1.74	16
Apr.	6.64	2.60	12	1.66	1.33	14	5.95	3.33	15	9.16	3.50	10
May	3.20	2.52	13	5.95	1.74	12	2.72	2.97	19	4.96	3.30	10
June	3.35	1.98	15	5.44	1.73	15	3.91	1.82	11	3.22	3.08	12
July	4.23	2.03	15	4.62	1.65	16	2.00	1.27	14	0.98	2.23	13
Aug.	2.38	1.86	19	5.81	1.57	20	2.28	0.90	16	4.58	2.08	28
Sept.	4.47	1.48	13	2.24	1.52	13	2.84	0.99	15	5.63	2.03	17
Oct.	1.98	1.44	15	5.84	1.62	20	6.13	1.14	13	0.14	1.93	15
Nov.	5.81	1.42	19	1.34	1.54	13	4.12	1.17	17	3.71	1.85	15
Dec.	2.35	1.47	14	3.72	1.82	18	4.18	1.52	13	2.16	1.76	15
Year	45.05	1.91	15	46.67	1.51	15	46.31	1.77	14	43.69	2.23	15

For purposes of ascertaining the average color of the water delivered into the reservoir, the following weighting, proportionate to area, was used with the data from the respective supplies:

	Sq. Miles.	Per Cent.
Nepaug River, including direct drainage to reservoir	26.57	83.4
Phelps Brook	2.90	9.1
Clear Brook	1.05	3.3
Reservoir area	1.33	4.2
Total	31.85	100.0

The color of the effluent water, in the following discussion, is that observed in samples taken in the Nepaug Reservoir near Phelps Brook dam.

TABLE 5.

COLLINSVILLE RESERVOIR — TABULATION OF COLOR OF WATER.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
1916	—	—	—	—	—	—	35	44	45	43	38	42	41.1
17	33	23	15	23	28	32	33	37	43	45	41	29	31.8
18	30	24	20	25	39	48	54	78	—	60	41	32	41.0
19	37	23	24	25	29	36	45	58	47	42	41	32	36.6
20	28	30	24	23	24	31	35	44	39	45	34	28	32.1
21	22	18	22	24	28	41	42	24	23	31	34	37	28.8
22	32	33	30	23	27	31	43	41	40	43	32	32	33.9
23	33	29	31	27	29	27	44	48	46	42	38	35	35.8
24	26	24	28	23	—	—	—	—	—	—	—	—	——
Mean	30.1	25.5	24.3	24.1	29.1	35.1	41.4	46.8	40.4	43.9	37.4	33.4	——
Max.	37	33	31	27	39	48	54	78	47	60	41	42	——
Min.	22	18	15	23	24	27	33	24	23	31	32	28	——

The color of the influent water is that obtained by the combination explained above, using the colors of water from the principal entering streams, together with zero color for rainfall on the reservoir surface. The annual averages are given in Table 6, and are shown also on Fig. 4.

Figure 4 shows the progressive decrease in color of the stored water at surface, mid-depth, and bottom.

Figures 5, 6, and 7, derived from the colors of the several entering streams and weighted as stated above, show several interesting conditions.

TABLE 6.

Nepaug Reservoir and Tributary Streams.

ANNUAL AVERAGE COLORS. NEPAUG RESERVOIR AND TRIBUTARY STREAMS.

(Reservoir filled in 1917.)

		NEPAUG RIVER. 26.57 sq. mi.		PHELPS BROOK. 2.90 sq. mi.		CLEAR BROOK. 1.05 sq. mi.		NEPAUG RESV.	
Year.	Rainfall Inches.	Disch. c.f.s. per sq. mi.	Color.	Disch. c.f.s. per sq. mi.	Color.	Disch. c.f.s. per sq. mi.	Color.	*Influent Color.	Effluent Color.
1917	43.04	1.86	32	1.52	41	1.71	15	29.9	35.7
1918	45.16	1,62	33	1.29	44	1.63	14	30.7	38.2
1919	49.58	1.93	33	1.68	45	1.94	17	31.0	31.1
1920	53.53	2.48	32	2.32	44	1.98	16	30.4	29.4
1921	40.70	1.57	31	1.60	37	1.91	15	29.2	25.8
1922	44.46	1.50	34	1.69	42	1.51	15	31.2	25.7
1923	44.20	1.87	29	2.01	35	1.77	14	27.2	26.2
Annual Average	45.81	1.87	32	1.73	41	1.78	15	29.9	†

* Weighted, and using color "0" for water falling on reservoir surface.
† Average would mean nothing because of changing conditions of reservoir.

While the effluent water has approximately the same color in both years, the color of the influent water depends very greatly on the amount of stream flow. Note that in 1922, with a comparatively high run-off during the entire season, the color of the influent water was considerably above that of

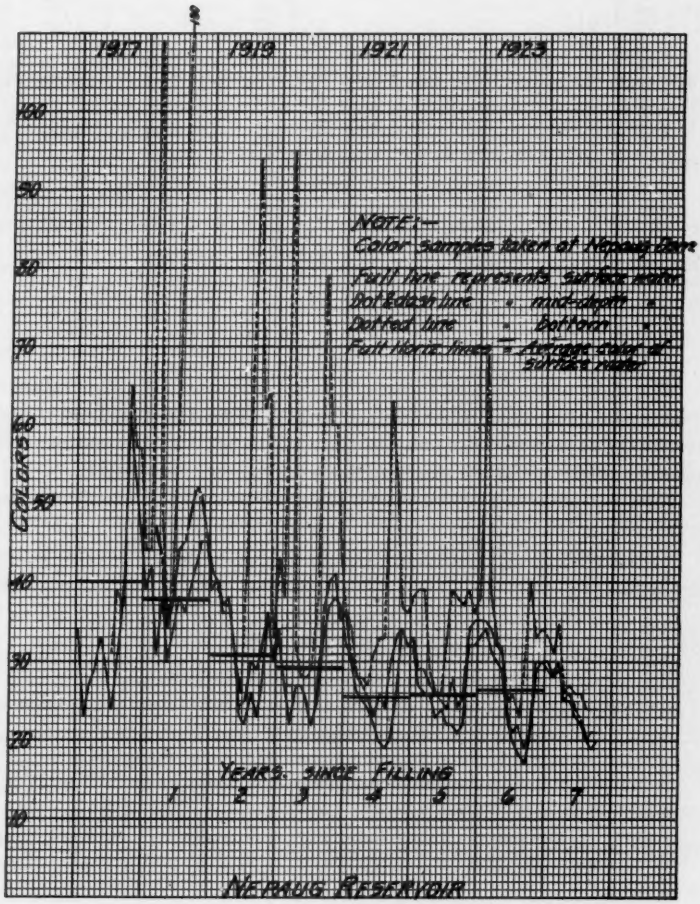


FIG. 4. — COLOR OF NEPAUG RESERVOIR WATER.

the effluent, while in 1923 during the period of low run-off, June to September, the color of the influent was only slightly above that of the effluent. Again, note that during the winter season, with ice cover on the reservoir and little action of sun or wind, the effluent water color is measurably above that of the incoming water.

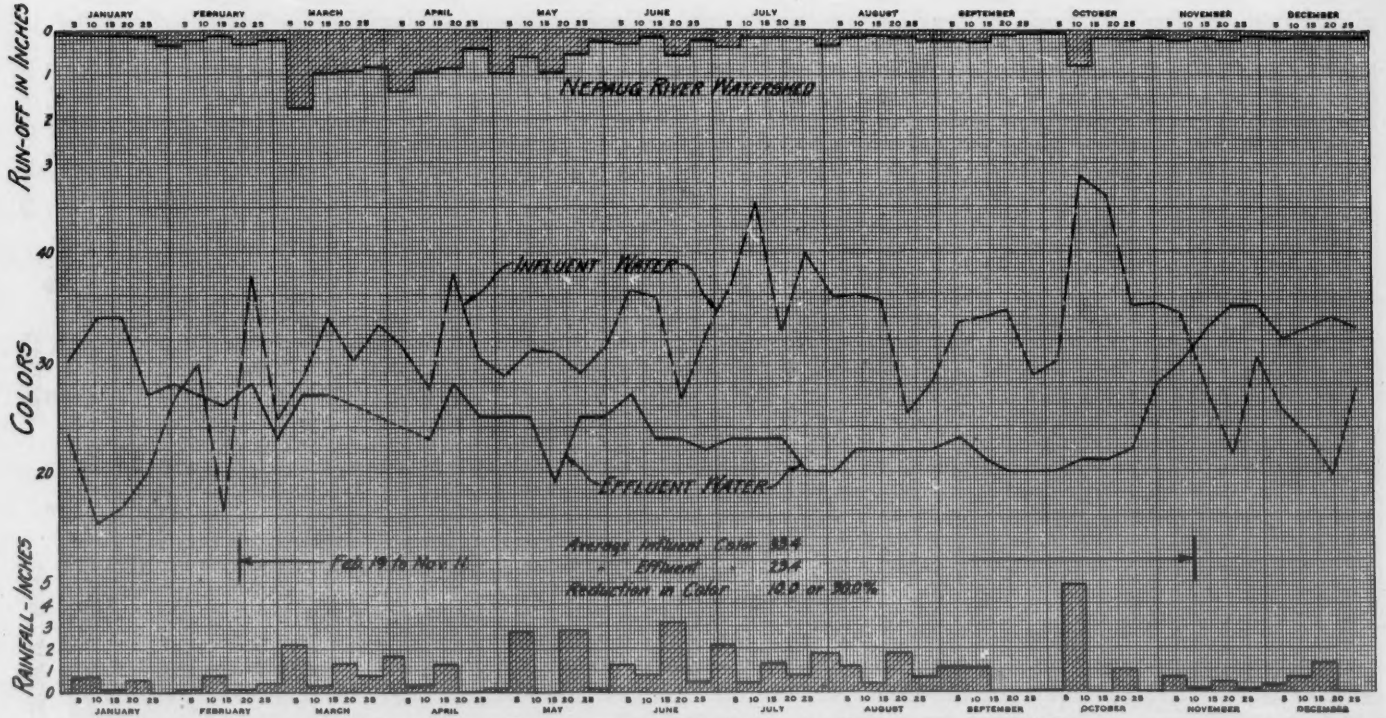


FIG. 5. — COLOR OF INFLUENT AND EFFLUENT. NEPAUG RESERVOIR. YEAR 1922.

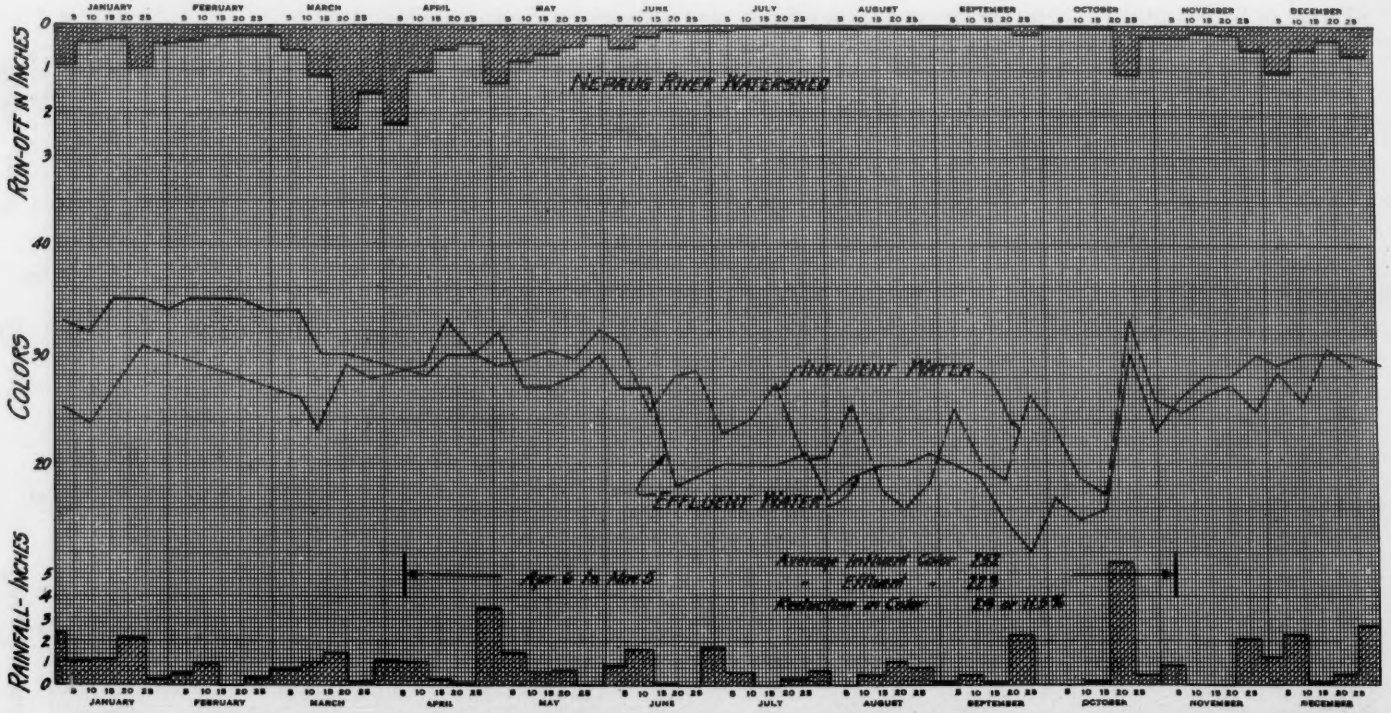


FIG. 6. — COLOR OF INFLUENT AND EFFLUENT NEPAUG RESERVOIR. YEAR 1923.

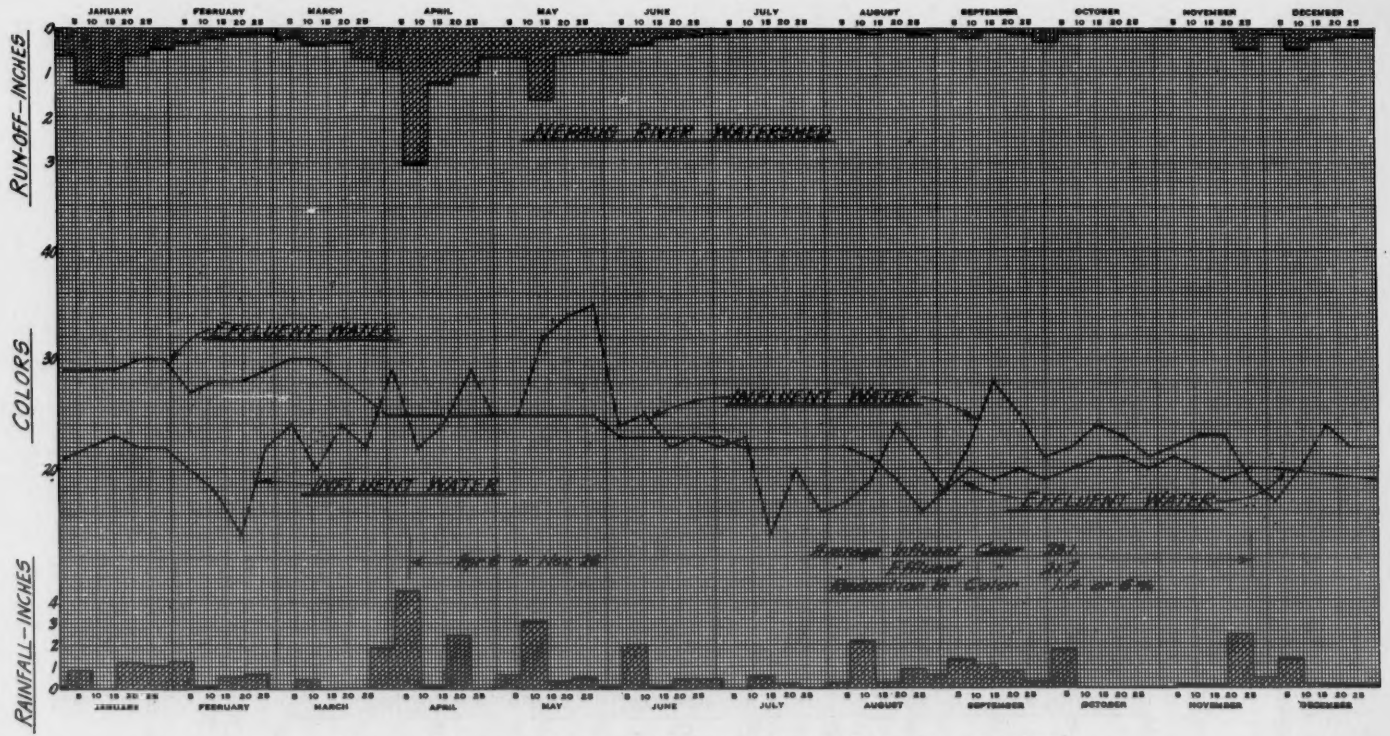


FIG. 7. — COLOR OF INFLUENT AND EFFLUENT. NEPAUG RESERVOIR. YEAR 1924.

On Fig. 8 is shown the changes in color of the stored water since the reservoir was put in commission.

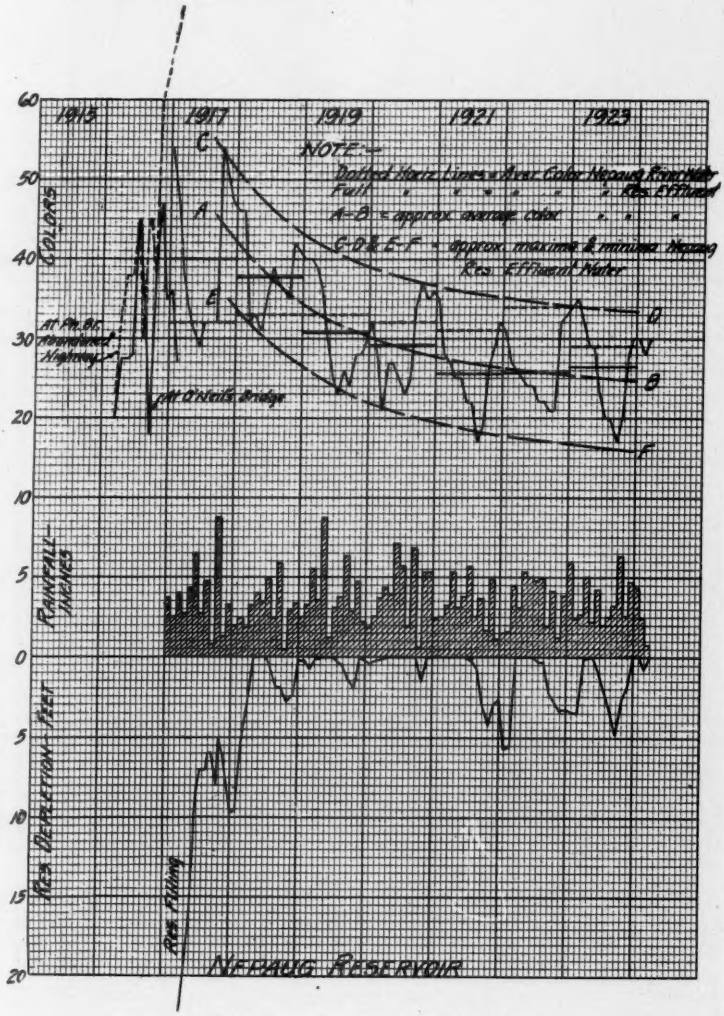


FIG. 8. — CHANGES IN COLOR OF STORED WATER.

The lines A-B, C-D, E-F, respectively, indicate mean, maximum, and minimum color range. The full and dotted horizontal lines indicate, respectively, the mean colors of the reservoir water and that of the Nepaug River, which supplies about two-thirds of the entering water.

Figure 9 shows the relative changes of color in the reservoir at different depths at the same time of observation and at different periods after the reservoir was filled, which was in the fall of 1917. Attention is particularly directed to the improvement in color of bottom water between September, 1920, and the same time in 1923.

As a record of conditions of percentage of saturation, temperature, and color of top, middle, and bottom water by months, Fig. 10 has been prepared for the year 1920, and for purposes of comparison records for May, June, and July, 1924, have been plotted on the same chart.

The color effect of comparatively small streams entering a large reservoir, be they excessively low or high, seems of relatively small importance, as it is probable that zero rainfall on the reservoir itself, or the discharge from springs directly into the reservoir, will neutralize the high colors from small streams flowing from swampy areas. While it is eminently desirable to improve watersheds by swamp drainage and so reduce color of the reservoir water, if it can be done to an appreciable extent, it is also desirable to study closely local influent conditions and decide if the result to be attained is worth the cost of the effort.

The following data are given for periods in which excessively high colors were observed in Phelps Brook:

The Phelps Brook watershed, of 2.9 sq. miles, drains a swampy area of perhaps a quarter of its entire drainage area. Clear Brook, with a drainage area of about 1.05 sq. miles, is entirely a glacial gravel and sand country, while the Nepaug Reservoir surface is 1.33 sq. miles in area, with an addition of about 2.25 sq. miles, steep slopes discharging quickly into the reservoir. The effluent colors in the reservoir are taken at the outlet chamber about 1.25 miles almost directly east of Phelps Brook outlet and in the path of prevailing winds.

The following rainfall records (inches) practically cover the whole drainage basin:

Week Ending.	Upper Phelps Brook.	Phelps Brook Dam.	Nepaug Dam.	Bakersville.
May 9	1.45	1.04	1.06	1.48
June 5	0.88	0.60	0.74	0.35
July 11	0.59	0.74	0.73	0.36
Oct. 24	5.11	4.56	4.91	5.20
Dec. 11	2.25	2.00	2.12	2.00

Week Ending.	Colors.		Total Influent (Weighted).	Effluent at Gate House.
	Phelps Brook.	Clear Brook.		
May 9	50	20	29.4	27
June 5	48	10	30.9	27
July 11	48	14	24.1	20
Oct. 24	50	21	33.1	30
Dec. 11	45	16	25.6	30

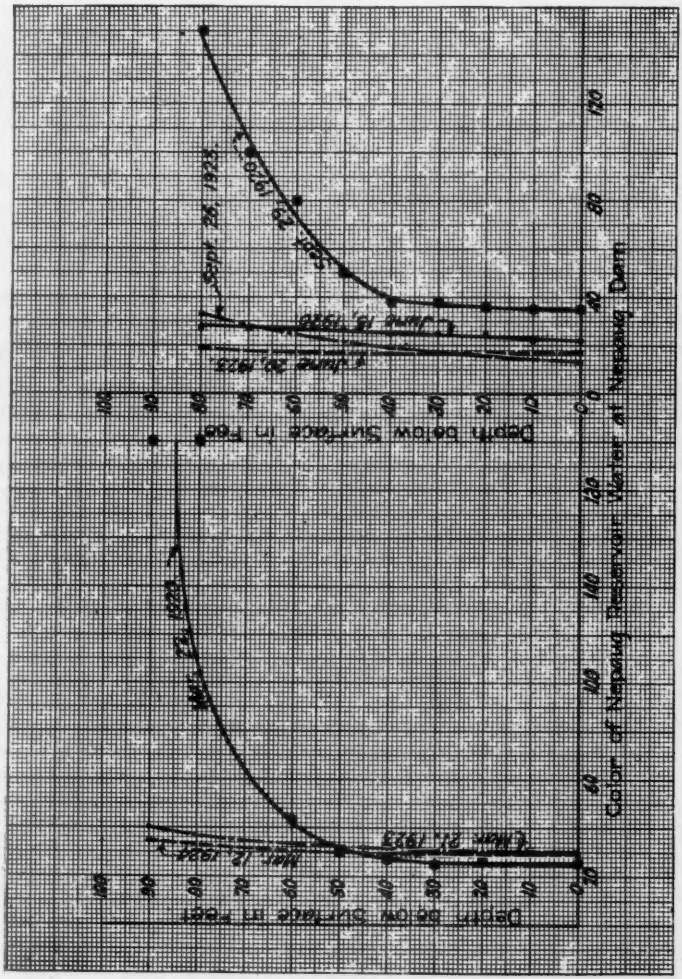
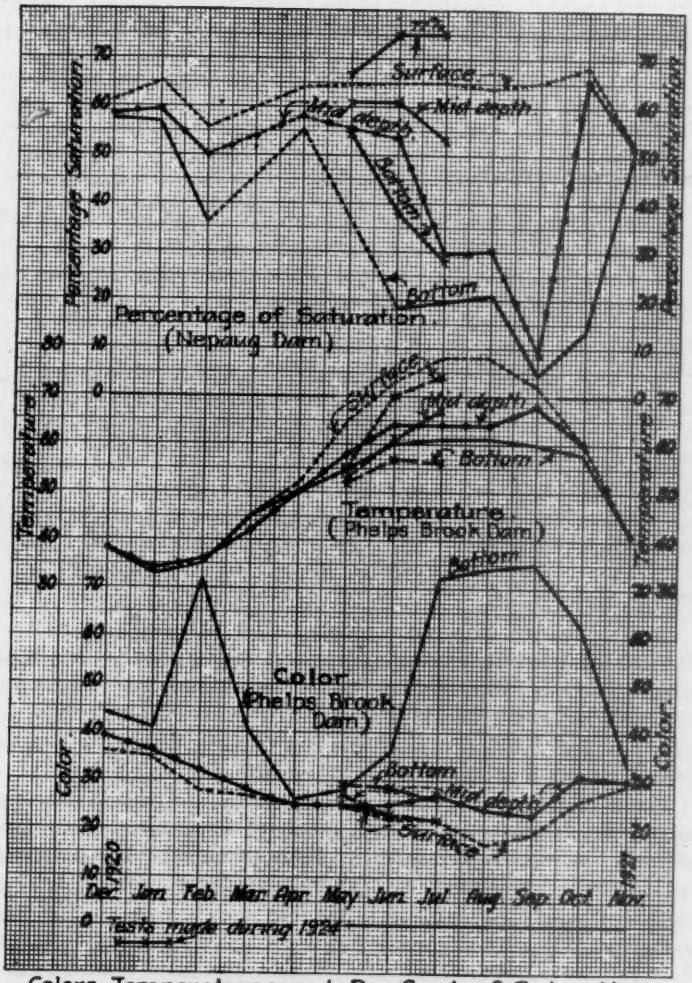

Color of Nepaug Reservoir Water at Various Depths
Depth below Surface in Feet
Depth below Surface in Feet
Sept. 25, 1922
June 18, 1923
June 30, 1922
Mar. 2, 1922
Mar. 21, 1923

FIG. 9. — RELATIVE CHANGES IN COLOR AT VARIOUS DEPTHS.



Colors, Temperatures and Per Cent of Saturation of Nepaug Reservoir Water.

FIG. 10. — COLOR, TEMPERATURE AND PER CENT. OF SATURATION OF NEPAUG RESERVOIR WATER.

The April 6–7, 1924, storm of 4.03 in., plus some snow accumulation, produced one of the greatest drainage basin disturbances of recent years, and probably has not been exceeded in the past 25 years. The following colors were observed immediately before the storm commenced, during the height of the discharge, and just after the discharge had returned to normal:

	April 4.	April 7.	April 9.
Nepaug River	26	48	23
Phelps Brook	30	45	35
Clear Brook	10	15	10
Nepaug Reservoir (at outlet)	25	25	25

There was no appreciable increase in color of the Nepaug Reservoir water in any of the weekly determinations from April 2 to May 28.

For colors at different depths the following determinations are given, for two localities where deepest water is found.

Depth below Surface. Feet.	May, 1924.		June, 1924.	
	Nepaug Dam.	Phelps Brook Dam.	Nepaug Dam.	Phelps Brook Dam.
Top	25	25	23	23
10	25	25	23	23
20	25	27	23	23
30	25	27	23	23
40	25	29	23	25
50	27	29 bottom	25	29 bottom
60	27		25	
70	27		25	
80	27		25	
90	27 bottom		26 bottom	

From what has gone before, it appears that in a reservoir similar to that of the Nepaug Reservoir of the Hartford water supply system, and with similar conditions of inflow, after five or six years the reservoir gets conditioned, as it were, although for several years longer there will be a gradual decrease in the color content of the stored water.

The data presented in this study substantiate the conclusions of that master of water supply phenomena, Frederick P. Stearns,—that when an unstripped reservoir is first filled the water acquires, after standing for a time, a considerable amount of color, chiefly from vegetable matters which have been flooded. Some of the color taken up is removed by the bleaching process which goes on in reservoirs where the water is stored for a long time. In the early years more color is taken up than is removed and the residual color is greater than the average color of the inflowing streams. As the years pass, the amount of coloring matter acquired from the bottom and sides of the reservoir diminishes, while the bleaching process is continually going on, so that after a term of years the result of storage is a decided diminution of the color of the water which enters the reservoir.

In regard to this color diminution in unstripped reservoirs, the period of attaining what may be called a normal color is somewhat uncertain, due

to local conditions, but the following are the results of study of some data which were made at the time when the probable future conditions in the Nepaug Reservoir were being considered.

Reservoir	Age When Normal Color Conditions Were Reached.
Holyoke — Whiting Street	9 years
Lynn — Glen Lewis	10 years
Lynn — Walden Pond	10 years
Marlboro — Millham Brook	4 years
Quincy	3 years
Southbridge — Hatchet No. 1	3 years
Springfield — Borden Brook	4 years
Winchester — Middle	6 years
Winchester — South	3 years
Average	6 years

DISCUSSION.

ROBERT SPURR WESTON.* It is a real contribution to our knowledge of the effect of a new unstripped reservoir upon water stored in it, to have this paper of Mr. Saville's. Ordinarily one is apt to base his judgment of the effect of storage upon either old reservoirs or reservoirs which have been stripped, and perhaps get an unfair opinion of their efficiency. These opinions are very apt to be rough when the effect of submerged swampy areas is not taken into consideration, for the time required to overcome the effect of vegetation upon the water is largely dependent on how long these peaty areas are going to give off highly colored matter to the water. Ultimately, assuming good sources of supply, ooze deposited by the water, as the result of oxidation of the organic matter, is going to act like a blanket on these deposits of peat and make the reservoir function about the same as a reservoir which has been stripped previously.

That is not always true, however. One reservoir — which our firm has been recently studying — near New Haven is an example of this. This reservoir covers an upland meadow. It is large, in fact, its storage ratio is 0.65, which is equivalent to 236 days' storage of the water that comes into it. This period in most reservoirs would give a color reduction of from twenty to forty-five per cent., while the actual accomplishment after a year or two is about the same as obtained at Hartford, although this opinion is based upon data which are not in any way as complete or reliable as Mr. Saville's data.

One explanation of the poor performance of this reservoir near New Haven is that one feeder enters near the reservoir outlet. Consequently there is an unequal distribution of the work which the water of the reservoir has to do in purifying — decolorizing — the water. If all the coloring matter be accumulated in one corner of a reservoir near where a feeder enters

* Of Weston & Sampson, Consulting Engineers, Boston, Mass.

and the oxygen in the rest of the reservoir is not brought in contact with it, the amount of work done in that portion of the reservoir where the concentration of coloring matter is greatest will not be anything like in degree what it would be were the entering water with its coloring matter equally distributed throughout the whole of the reservoir.

Now, strangely enough, Phelps Brook, one of the feeders of the Nepaug Reservoir, discharges into its easterly arm — that is the one which is nearest the intake — and this is separated, as Mr. Saville has stated, from the reservoir receiving the larger inflow by a divide which is submerged when the reservoir is at normal elevation. Consequently, is it not reasonable to ask if the peculiar shape of this reservoir, and the relation between the locations of feeders and outlets, are not partly, at least, responsible for the unexpectedly low color removal by this reservoir?

Of contrasting shape is the long and narrow Hobbs Brook Reservoir, (Cambridge, Mass.) which removes nearly 70 per cent. of the contributed color during about 335 days' storage. On the other hand, the shorter Borden Brook Reservoir, (Springfield, Mass.) whose geology is similar to that of the Nepaug Reservoir, removes but 23 per cent. of the color during about the same period.

These apposite figures make one realize that the storage period, or ratio, is not the only criterion for estimating the color-removing effect of a reservoir, but the character of the incoming water and the shape and nature of the reservoir bottom must be carefully considered as well.

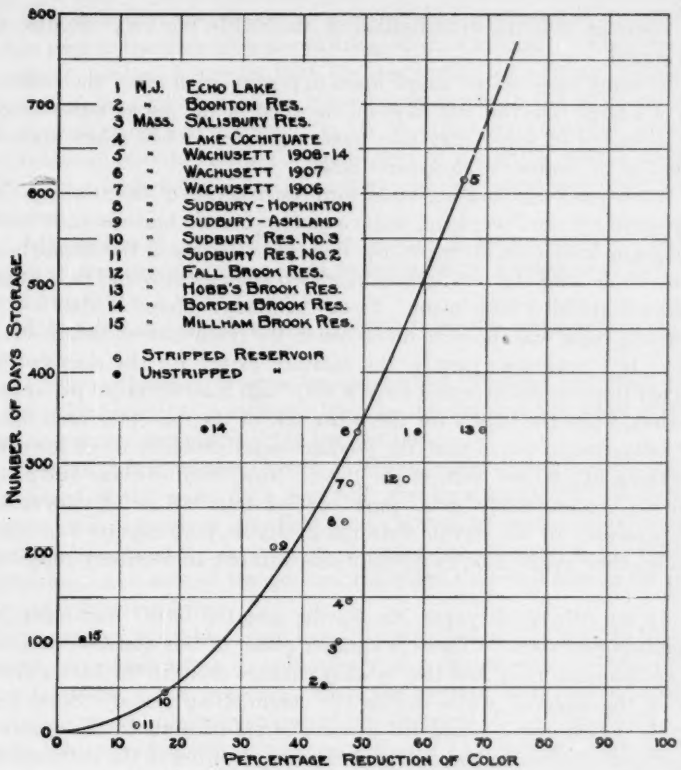
Quite recently the speaker's firm estimated the reduction in the color of the water from the west branch of the Passaic River if stored in an unstripped reservoir of high natural character and for various periods. Our estimate was as follows:

50 days,	19 per cent.	200 days,	38 per cent.
100 days,	27 per cent.	250 days,	42 per cent.
150 days,	33 per cent.	300 days,	46 per cent.
	250 days, 50 per cent.		

These values are considerably higher than those given by Mr. Saville, and it is not thought that the proposed reservoir under consideration is any better in character of bottom than the Nepaug Reservoir. Yet it is confidently expected that the quoted values, or better, will be secured in practice.

The following diagram shows the curve from which the figures given in the table have been derived and on the diagram there are also data which have been gathered from practice and from a paper by Ralph H. Stearns, which was published in this JOURNAL. Most of those values are higher than those assumed for the curve, and considerably higher than those recorded in Mr. Saville's paper.

I have read Mr. Saville's paper very carefully, and have tried to explain why the percentage removal of color in such a large and good reservoir



Reduction of Color in Reservoirs.

is so low. This difficulty is more important in view of the fact that, ordinarily, the observed percentage reductions are really higher than the actual, because while one gets a fair average by ordinary sampling and determination of the color of the effluent of the reservoir, one usually fails to obtain a fair average of the color flowing into it. This is because the streams are sampled but not the ground water entering the reservoir. Assuming that the dam shuts off the whole valley, and 50 per cent. of the water runs in with the stream and 50 per cent. soaks in through the ground, the inflowing color would be approximately half of that observed.

Mr. Saville. I would just like to say, in speaking about Mr. Weston's discussion, that I inadvertently omitted to state that Mr. Weston also was called in as a consultant and made figures that closely approximated those of Mr. Stearns.

Stephen DeM. Gage.* Mr. President, I did not expect to come to this meeting and, therefore, have prepared no discussion. I do want to

* Chemist and Sanitary Engineer, Rhode Island State Board of Health.

say, however, that this contribution of Mr. Saville's is very valuable and very useful.

In many cases we are called upon to predict what effect the construction of a large reservoir will have on the color of the public water supply. The diversion of water may also have a greater or less effect upon the quality of the water in the streams below.

A few years ago, in connection with construction of the new impounding reservoir of the Providence water supply, a certain manufacturer asking damages on account of diversion, claimed that the color of the stream below the reservoir would be very largely increased and that it would be necessary for him to install a filter plant. In the testimony offered in this case one surprising thing was the wide difference in the prediction of future stream color. If I remember rightly, the sanitary expert for the manufacturer testified that the water would have a very high color 80 or 90 per cent. of the time, while the expert for the other side of the case presented figures and estimates to prove that the stream would probably be of low color, something like 90 per cent. of the time. Now, both of these two predictions were based largely on the same existing data, but as full data such as that presented by Mr. Saville were not available, both experts were forced to make their predictions on assumptions, without all necessary supporting facts.

In the title of his paper Mr. Saville uses the term "and other phenomena in reservoirs." There is another phase of this question, which he has not touched upon, and that is what changes occur in the bacterial content of the reservoir water during the conditioning period. Some years ago Mr. Clark and I conducted a series of experiments at the Lawrence Experiment Station to find out what changes occurred in the bacterial content of water during storage. We found that when a water is transferred to a new container, the numbers of bacteria increase enormously for a time and then very slowly decrease to a point as low as, or lower than, they were at the start. These phenomena appeared to be entirely independent of the size or shape of the container. We used bottles, carboys, and tanks of various sizes; even going to the extent of filling some of the containers with sterilized glass beads. In every case the same general bacterial curves were obtained. We then made experiments to imitate water-works reservoirs in actual use, withdrawing a portion of the water in our container each day and replacing this with new water. In every case the same phenomena occurred, — the bacteria went up at first, and then declined. What actually happened was that the transfer of the water destroyed the bacterial balance and that a readjustment of bacterial forces took place with the establishment of a new bacterial balance. From all available evidence I believe that these same phenomena take place in any new water-works reservoir, and that the observed results during the conditioning period are in a considerable measure the result of natural bacterial processes.

The reduction in color in a reservoir during storage is undoubtedly due in part to the bleaching or oxidizing effect of sunlight. There is every reason to believe, however, that the destruction of organic matters by bacterial fermentation is also a considerable factor in the color reduction which results from long storage. As Mr. Weston has pointed out, the shape of a reservoir, and the relation of the feeders to the outlet, would undoubtedly have a large influence on the color; and this would also apply to the bacteria.

MR. WESTON. May I ask Mr. Saville if he remembers what the period of storage in the reservoir is under ordinary conditions of flow, with mean run-off?

MR. SAVILLE. I think it is somewhere in the neighborhood of 225 days.

I believe that Mr. Weston has touched on two most important points in the color history of a reservoir, that is, the shape of the water area and the topography and character of the bottom.

I think that Professor George C. Whipple mentioned that the vertical movement of the water in a reservoir, due to seasonal and temperature changes, was probably of less effect than a lateral movement along the whole depth and length of the reservoir in changing the character of the water by a scouring, as it were, of the bottom and sides, thus well mixing the entire contents of the reservoir.

Regarding what Mr. Gage has just spoken of, — the actions that mill owners sometimes bring, — reminds me of a similar case to that, not far from Hartford, a few years ago, when the town of East Hartford, Conn., took their water supply from one of the branches of Roaring Brook. Mr. Walsh is here, and he will perhaps correct me if I am wrong. But, anyway, that was one of the principal causes of discussion that was brought up, — that the town of East Hartford was to take the best brook, the best color of water from the stream, and therefore the mill owners would suffer very greatly. I think that they got damages in proportion to their cry.

Mr. Gage's remarks, about the increase in bacteria, recalls to my memory the fact that all of the drinking water that was used by the canal employees on the Isthmus was sterilized and condensed water. And at one time it was found that, although everything was done to keep it free from contamination, yet the bacterial content in that water was very high — very, very high — and on looking around for a reason, the outlet to the condenser, which had not been touched by human hands, was found to have a tremendous number of bacteria lurking therein. These, it was decided, came, probably, from the air.

PRESIDENT TAYLOR. I think it would be interesting if Mr. Gage would tell us about the change in the bacterial condition from the time the stream entered the reservoir. How long does it take to bring it back to a balance again, Mr. Gage?

MR. GAGE. I cannot answer that question definitely. Most of our

work at Lawrence was done in small volumes. If we take a bottle or a tank or a standpipe and fill it with water the bacteria begin to multiply almost immediately. Now, if we let that water stand without any change in contents there will be a gradual reduction in the number of bacteria. It will take two or three weeks or, perhaps, a month for the bacteria to go up to the maximum, and then there will be a period of, perhaps, six to eight months or, maybe, a year or two, before they come down to where they started. That is, we get a sharp rise and then a very slow drop in the bacterial curve. Our experimental reservoirs, in which there was an exchange of some water, developed essentially the same type of curve; that is, the fact that there was water flowing in and out did not seem to affect the shape of the curve. It is reasonable to assume that this same phenomenon takes place in large storage reservoirs, although there are other factors which would also have their effect. This is of course largely theory. I do not know of any one who has actually repeated these studies with a large reservoir under actual working conditions. Some of the apparently abnormal bacterial results obtained from large reservoirs, however, are readily explained on this hypothesis. Houston's results on the London reservoirs appear to show much the same phenomena.

From the results of color, and other determinations, it usually takes one to two years for the conditioning process in a new reservoir, and we probably will not be far wrong if we say that a similar period will be required to reëstablish a bacterial balance.

GEORGE C. WHIPPLE.* I am glad that Mr. Saville has put on record the facts in regard to the color of the water in the Hartford reservoirs. One of the difficult things for a water-works engineer to do is to estimate in advance what will be the color of water from a certain stream after a dam has been constructed and the water stored. Data such as Mr. Saville has collected help us in the solution of such problems. If I am not mistaken, estimates were made of the probable color of the new Hartford water supply in advance of the construction of the reservoirs. It would be interesting if Mr. Saville would give us these estimates for comparison with the figures which he has given.

In his paper he does not say how frequently the color observations were made. Changes in the color of streams, especially small streams, occur so rapidly that weekly or monthly determinations are of little value as a basis of estimating the probable future color of stored water. Daily observations of color, accompanied by daily records of stream flow, are desirable. In 1903 when the investigations were made for the future water supply of the City of New York, sampling stations were established on practically all of the streams in the eastern part of New York State and arrangements were made for the collection of daily samples. These were of great value as a basis of estimating future quality. Many years before that, when Desmond FitzGerald was making investigations of the color of

* Professor of Sanitary Engineering, Harvard University. Professor Whipple died on November 27, 1924.

the Sudbury water, the same need for frequent sampling became evident. The stream entering what is now the Ashland basin was fitted with a weir, so that daily records of the flow as well as daily color of the water could be obtained. When, by using figures of this sort, a weighted average of all the water entering the basin was obtained, and when due allowance was also made for the water entering the reservoir through the ground, and for evaporation, it was found that the computed color agreed quite well with the actual color observed in the reservoir at the lower end. Studies of this sort have convinced the writer that too much emphasis is sometimes given to the so-called bleaching effect by sunlight. Bleaching does occur, it is true, but it is common to attribute solely to bleaching a color reduction which results in part from other causes. If, as seems likely, flood waters are to be stored and used as sources of supply more than they have been in the past, daily records of color, in place of weekly or monthly records, will be needed.

In connection with the absorption of color from vegetable matter, it may be set down as a fact, well established, that fresh vegetation contributes more color to water than old peaty matter and humus. This was shown conclusively by experiments made for the New York Board of Water Supply by Thaddeus Merriman, the writer having given some advice in regard to them.

The element of iron plays an important part in all coloring matter. Chlorophyll in plants, one of the most important and interesting substances in the world, is thought by some to be dependent upon iron for its power of building carbonic acid into starches and sugars with the aid of sunlight. Iron plays an important part in the brilliant colors of our autumn foliage, and in the same way iron plays a part in the color of water.

Stagnation of the water in reservoirs is also an element and, in this connection, I am tempted to correct a conception which many have in regard to the so-called overturn of water in reservoirs. Most people visualize the overturn of water during the spring and fall as a vertical movement due to temperature changes which affect density. To some extent this is true, but the greater movements of the water are horizontal and are controlled by the wind. In a stagnant reservoir during the summer the wind blows the surface water in one direction and there is a return current at the level of the so-called transition zone between the layers of stagnant and circulating waters. In the fall, as the temperature cools, the circulating layer becomes thicker and the return horizontal currents occur at greater depths in the reservoir, until finally, when the "turn over" occurs, the return currents actually wash the bottom of the reservoir and thus carry into circulation any colored water which has accumulated there.

CHARLES W. SHERMAN.* The Ashby Reservoir of the city of Fitchburg, built in 1915, apparently reached a permanent condition as regards color in about three years.

This reservoir is on Willard Brook, a tributary of Squanacook River.

* Of Metcalf & Eddy, Consulting Engineers, Boston, Mass.

The waters are diverted into the upper part of Falulah Brook, from which a part of the city's supply was already obtained, through a small basin with no appreciable storage. It was originally intended that one or two storage reservoirs should be built on Falulah Brook before the Ashby Reservoir was taken, but legislative restrictions made it necessary to follow the other course. Storage in the basins yet to be built will doubtless result in a further decrease in color of Ashby Reservoir water in the future. At present, the water flows in the natural brook channel about 2½ miles to the point of diversion into the pipes.

The site of Ashby Reservoir was not stripped, but all trees and bushes were removed and the roots grubbed and burned. It has an area of 153 acres, a greatest depth of 22 ft., and a storage capacity of about 700 million gal., and receives the water from a catchment area of 2.16 sq. miles, according to the topographic map of the U. S. Geological Survey. About 85 acres of the site were occupied by a mill reservoir, 50 years or more old, and the coloring matter in the soil must have been thoroughly dissolved from this part of the bottom. About half of the remainder was swampy land, which would be likely to contribute considerable color.

No records of the colors of the water of the tributary brooks are to be had.

The Ashby Reservoir was first filled in 1916. The color of the water in the bottom when filling began was 73; later in the season it was 100.

The colors in 1917 were 150 in the spring and 65 in the fall; in 1918, they fluctuated betweeen 55 and 90; in 1919, between 25 and 47; in 1920, between 21 and 50; in 1921, between 15 and 47; in 1922, between 18 and 52; and in 1923, between 20 and 65. The normal or average color is about 30, and this has remained nearly constant since about 1920. It required about three years to reach this normal, including the year in which the reservoir was first filled.

The fact that more than half the area of the reservoir consists of the bed of the old mill reservoir may have had considerable effect, both on the period of time required to reach a stable condition and on the colors of the water during that period.

SOME RESULTS OF PIPE CLEANING.

BY BURT B. HODGMAN.*

[*Read February 10, 1925.*]

The first experience of the writer in cleaning water mains was at Wheeling, W. Va., in 1907, where we had a contract to clean several miles of 4 in. and 6-in. pipe. These mains had been carrying raw Ohio River water for many years and were very badly incrusted with iron scale and also contained large deposits of mud. The equipment which we used was very crude, as were the machines, and we considered we had done good work with one crew if we cleaned 2 000 to 2 500 ft. in a week. Our idea at that time was to restore the original diameter of the pipe, get all the scale and mud out regardless of the condition of the pipe; and because some of the scale was hard and adhered to the pipe very tightly, we constructed what we called "saw tooth" blades, which were very sharp and very stiff, so that we would be sure to remove everything. We did. We removed the scale and some of the tar coating which remained under the scale. We soon learned, however, that the tar coating which remained under the scale was extremely important as a protection to the metal from the water.

We spent several years in time and a great deal of money in experimenting to overcome the difficulty of removing hard scale from mains without scratching the remaining coating. We have tried various metals and various forms of blades and carriers to keep the blades from actually touching the metal and, as a result, we believe that today we can clean any kind of scale from mains without injuring the coating that actually remains under the scale. I would say right here, however, that there are certain waters or, perhaps certain chemicals in waters, that tend to actually destroy the coating so that however careful we might be in removing the scale from the pipe, we would find no coating underneath.

The trouble with the blades was only a small problem compared with the difficulty we encountered in obtaining machines to overcome the various obstructions which stand in the way of successful cleaning of mains. I have made no count, but I should estimate that we built somewhere in the vicinity of twenty to twenty-five different types of machines before we arrived at the standard which we are using today and which we feel meets most of the conditions found in underground water systems. Our experience has taught us that when we send an equipment to clean pipe in a certain city, we can plan what kind of machine and what kind of blades to use, as we know most of the cities in the United States and the character of their water supply, and the kind of trouble we are liable to encounter.

* Of National Water Main Cleaning Co.

The writer was asked to tell you some of our troubles and I shall try to do this. We have had troubles, as everybody has, and of various kinds. We have cleaned mains under 30 or 40 ft. of water, and these mains were supposed to be fairly straight in alignment, but we found them 8 ft. deep in one place and 40 ft. deep 100 ft. away. We have cleaned mains that were supposed to be in the street and found them in every place but the street, and nobody knew where the pipe was located until we had finished our work. We have cleaned mains and found that the carrying capacity was seriously depreciated almost before we left town. I suppose you have all heard of our experience in Charleston, S. C., where we cleaned a force main, reducing pumping pressure from 125 lbs. to 75 lbs., and it was back to 125 lbs. inside of a year. This is no reflection on pipe cleaning, but is due entirely to local conditions. The water attacks iron very rapidly and this is a long line of pipe which requires comparatively little roughness to create the friction.

In St. Louis, Mo., we cleaned nearly 150 miles of pipe and guaranteed to restore the carrying capacity to within 5 per cent. of that of new pipe, Weston's tables on flow being used as a basis. The city had their own pitometer department test the capacity, and it so happened that one section of 6-in. line was not tested for several months after the cleaning, and then the test showed somewhere around 80 per cent. of the carrying capacity of new pipe. This pipe was re-cleaned and showed 97 per cent. of the capacity of new pipe. About six months later the pipe was tested again and the carrying capacity was 78 per cent. of new pipe. That same line has been tested at least once a year for the last four years, and the carrying capacity has dropped until this past year it was 68 per cent. of new pipe. Before cleaning, it had only 44 per cent. of the carrying capacity of new pipe. There were several lines of 6-in. pipe in St. Louis which seemed to act as this one line did. The conditions found there, however, were extremely difficult for us to improve. In the first place, many years ago a great excess of lime was used in treating the water and this lime was not thoroughly settled from the water before it was turned into the distribution system, and therefore formed a heavy scale of lime on top of the iron corrosion which was already in the pipe.

The writer took sections of the St. Louis pipe and removed the scale by hand very carefully and found under this scale only a dull black iron surface, but when we had to clean this lime out, very stiff blades were required. If they were not used we could not reach the 95 per cent. efficiency, but in reaching the 95 per cent. efficiency, the metal was uncovered in such a way that the water attacked it very rapidly again. Now, the peculiar condition existing in St. Louis was that the larger mains, of which we cleaned many miles, did not show the same trouble after cleaning, for in four years tests on carrying capacity of these larger mains have shown the drop to be from 99 per cent. immediately after cleaning to 88 per cent. in one case, and 85 per cent. in another case, and 80 per cent. in another. However,

we did find that many of the larger mains contained less of the lime scale than the smaller mains, due in a measure to the fact that in some of the larger mains there was a heavy deposit of soft mud which protected the pipe from the action of the lime on the coating. A study of the St. Louis situation revealed the fact that even under the worst conditions, after the first four or six months the action on the pipes reached the point where the scale formed very slowly and only in the case of the 6-in. pipe was the depreciation serious. Four years after cleaning they still carried 55 per cent. more water than they carried before the original cleaning.

We have in our files letters from a great number of cities showing that since the original cleaning they have had no more trouble with their mains than they have had with new mains put in at the time the cleaning was done. In some cities one cleaning of the mains has removed the trouble so that for a period of eight or ten years they are still amply satisfied with all the work that was done and have no further need for our services. In one city the Board of Fire Underwriters made a survey in 1909 and recommended extensive replacements with larger mains. It is our understanding that none of these replacements were made, but they cleaned from ten to twenty miles of pipe each year and in 1915 the Board of Fire Underwriters made another survey and gave them a "clean bill of health."

In conclusion, I wish to bring before you the fact that it has been our aim to study the conditions existing in the various underground systems, meet those conditions with the best scientific practice, not only from the standpoint of removing the scale, but from that of using the very best and most efficient equipment so that the mains would be shut off for the least possible time.

We have been cleaning pipe for twenty years. We have studied conditions and have carried our superintendents throughout the year, whether we had work or not, and are today giving a service to the water departments of this country just as much as the water departments are giving a service when they keep water at their hydrants.

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TOPICAL DISCUSSION.

Protection of Water Pipes and Appurtenances in Exposed Locations.

[*Read March 10, 1925.*]

George H. Finneran.* The natural location for a water pipe is at a suitable depth underground, resting upon a bed of uniform resistance.

There it is protected from frost, shock and vibration, from variation in atmospheric temperature; and if not disturbed, or the earth removed from under it and some rigid bearing substituted, it will render service for its natural life without unusual incident.

Certain conditions, of course, expose it to corrosion, internal and external, also electrolysis; and a recent event reminds us of a very rare, but very serious danger, — that of earthquake.

Whether a pipe underground is more liable to damage from earthquake than one overground is a question difficult to decide. Data on this subject, hereabouts at least, are scarce. Possibly in California they are able to speak with authority on the matter.

During the unusual sensation of the quake, there were two thoughts that occupied my mind almost simultaneously; one for my own personal safety and the other for the pipes in our system. I had a picture of a great many breaks occurring in different locations and in pipe lines of large and small diameter.

I immediately called up our emergency headquarters and as I listened to the telephone connections being made without difficulty or delay, I felt somewhat relieved; and when I got my man and asked him if he had received any reports of broken mains and he answered that he had not, I felt doubly relieved. However, I was not entirely at rest until I learned that the pressures indicated by the high and low service gages were normal.

The possibilities of a severe earthquake shock are quite disturbing, to say the least, and provisions for meeting them from a water-works standpoint should make an interesting and valuable study.

To revert to the subject: Almost all cities are more or less intersected by railroads and waterways. To afford means for foot and vehicular traffic, these waterways and railroads are bridged over. The bridges serve in a great many cases to provide for the carriage of water and gas pipes, and electric and telephone cables.

In Boston there are many such pipe crossings. To be exact, 102 pipe lines are carried on bridges over railroads or water.

They cross usually on one side of the bridge, either under the foot-

* Superintendent, Water Service, Boston, Mass.

paths, between the footpath and vehicle lane, or just outside the bridge-way proper, supported on arms or brackets attached to the bridge-structure. Where there are draws in the bridges, the pipe line is carried under the draw-way by means of an inverted siphon enclosed in masonry or wood.

In carrying a water pipe across a bridge, provision should be made to protect it from freezing and from the impact of wildly driven automobiles, tugs, lighters, etc.

The liability to freeze varies according to several factors, — the diameter of the pipe, the velocity of flow during the period when consumption is at its lowest, the exposure of the pipe to wind, the position of the pipe in relation to the sun, etc.

For many years it was the practice of the Boston Water Works to enclose its exposed pipes in double wooden boxes. The inside box was square in shape, simply made, and fitted close to the pipe. The outside box was sheathed and had a pitched roof. If the box was exposed to the roadway a hard pine timber was placed outside as a fender.

This type of box served the purpose for many years until the price of lumber, paint, and labor advanced, and the small boy became more destructive. It became more costly and difficult to keep the boxes in certain localities in repair. As soon as a slight opening was made in any part of the box, it was only a short time when the rest of it was ripped apart and the lumber stolen. They frequently caught fire, and we found that where large pipes were enclosed over railroads that the blast from the locomotives loosened the flooring and then the interior of the box became filled with smoke, soot, and cinders.

The soot lodged on the pipe, and any water that leaked through the box would mix with the soot and form an acid that ate into the iron pipe, pitting it quite deeply and causing us some apprehension as to how long the pipe would last. The loosened floor boards fell upon the tracks and made more or less trouble. So it was decided to give the pipes ventilation and remove the boxing entirely from those directly exposed to the blast of locomotives.

We have watched them closely during cold spells, testing them by means of the air valves, and so far have not noticed any signs of ice within, not even during the winter of 1917–18. These pipes range in size from 18 in. to 42 in. We attribute the freedom from ice to the constant movement of the water. Care has to be exercised to keep all valves open on both sides of the bridges.

We have not removed all the wooden boxes, and many of the pipes, large and small, still have that type of protection. It serves its purpose well in certain places, removed from locomotive gases, hot cinders, and the small boy.

We are, however, replacing the wooden boxing where it is worn out, or where the pipe line is relaid, by a sheet metal cover over a coating of felt. We find this more durable and less bulky than the wooden box.

It consists of a covering of felt 3 in. thick wrapped around the pipe. Over that is a layer of tar paper to keep the felt dry. The tar paper and felt are kept in place by copper wire. Over that is a galvanized sheet-iron cover properly rolled to fit snugly over the felt. Wooden collars 3 in. deep and 2 in. wide are placed around the pipe at frequent intervals to support the metal cover.

The cover is screwed to the collars. Along the top is a sheet-metal ridge, about 1½ in. high, to discourage walking or sitting on the pipe. Where the pipe is exposed to vehicular traffic the usual 10 x 10 hard pine fender runs along outside. Where the pipe goes below the surface of the ground on each end of the bridge, the metal cover follows it for a few feet. To prevent corrosion, and also to protect it from knocks of various kinds, a jacket of brick freely coated with cement is placed outside the sheet iron for a distance of about 2 ft. above and 3 ft. below the surface of the ground. Although galvanized, the sheet iron is painted with a priming coat of red followed by a coat of color, usually battleship gray.

A recent special treatment of a pipe exposed to the cold was on Neponset Bridge where the pipe ran under the sidewalk in a space about 20 in. deep, provided for gas and water. The bottom and sides of the pipe-way were of concrete and the top was an artificial stone walk reinforced with wire mesh. We filled the entire space 20 in. deep and about 5 ft. wide with shavings. We have used shavings in several places and found them satisfactory.

We have also used granulated cork. Cork is especially good, as it does not absorb moisture.

To provide protection from automobiles we plan, as far as possible, to lay the pipe in or under the sidewalk of the bridge, using the bridge girder as a fender. If it is necessary to expose the pipe to auto traffic we place a timber outside and curve it around both ends of the pipe where it comes up from underground.

Pipes passing over waterways are exposed to bumps from tugs, lighters, barges, etc. Piling and timbering may be so arranged in the form of fenders as to afford suitable protection.

Joints are liable to leak, due to vibration of the bridge-structure. This varies with the design and method of bridge construction and the kind of traffic passing over it.

A most frequent and serious trouble is settlement at the abutments. The pipe on the bridge-structure does not settle, but the pipe in the ground where it rises to mount the bridge has a tendency to settle and pull away from the abutment. As a rule, the approach to a bridge is a fill of loose gravel or sand, and the vibration from bridge traffic overhead and railroad traffic underneath keeps the sand and gravel in a state of movement. It compacts or crawls and, moving away from under the pipe, causes the pipe to sag. The joints strain and sometimes blow out. Furthermore, there is an unbalanced pressure to contend with.

To counteract all this, the inclined pipe between the upper and lower levels should be strapped together and anchored to the abutment. Concrete piers should be placed back of the curves and otherwise the pipe made as secure as possible. We have had some very serious leaks due to pipelines separating at bridge abutments.

Because of their value and importance, large feed lines should not be exposed to the risks of crossing bridges. In Boston we are carrying them under the railroads and waterways by means of inverted steel siphons enclosed in concrete.

Steel may be considered as a better material than cast iron, to use in large lines crossing over bridges, as it is practically self-supporting. It is, however, more difficult to repair if damaged. On the other hand, cast iron resists corrosion from locomotive gases, moisture, etc., better than steel.

From my experience with pipes in Boston, I am inclined towards the following conclusions:

If practicable, all pipes, large and small, should cross railroads and waterways under and not over.

If not practicable, or for some good reason it is not desirable to pass under, the pipes, if of large diameter, should be made of steel, well supported and strapped, protected from impact with moving objects, coated to resist acid fumes and liquids, and a velocity of flow maintained within to prevent freezing. If of 12 in. or less in diameter, they may be made of steel or cast iron, properly supported, strapped at points of unbalanced pressures, covered with some non-conducting material, protected from shock or impact with moving objects, and a circulation of sufficient velocity maintained within them to prevent freezing.

There are places where it is impossible to give pipes a cover of more than 2 or 3 ft. of earth or pavement. The situations I have in mind are where distribution mains and laterals pass over large conduits, sewers, or subways.

As a rule, the length of pipe thus exposed does not exceed 35 or 40 ft. In such cases we use with satisfactory results an insulating compound consisting of granulated cork mixed with hot pitch. The cold-storage people use the same mixture around their brine pipes to keep them cold, or, more properly, to prevent the brine from absorbing the heat of the ground.

A roughly made form is placed around the pipe, on the bottom and two sides, providing a space of about 6 in. all around, to be filled with the mixture. About 6 gal. of pitch are mixed with 2 bushels of medium-sized granulated cork. Two kettles are used, one in which the pitch is melted and the other in which the hot pitch is mixed with the cork. Pour from the melting kettle into the mixing kettle. A slow fire is kept under the mixing kettle. After mixing and while in a fluid state it is ladled into the form and the latter filled until the pipe is completely covered. The compound will harden when cold.

The cold-storage people place the mixture around our service pipes

where they lie in proximity to their brine pipes. They do this at their own expense, as we charge them for thawing should a service pipe freeze near one of their conduits.

It has been of great help in several localities where our service pipes were laid shallow, upon rock, and covered with a loose stone back-fill. Winter after winter these pipes would freeze with provoking regularity until finally we enclosed them in boxes, 4 in. x 4 in. inside dimensions, filled with cork and pitch. Since then we have forgotten they exist.

We have also used this compound to protect post hydrant pots where they set close to an area, or catch-basin.

With regard to the protection of hydrants, there are two dangers to guard against — frost and automobiles.

Frost, of course, comes first. As we all know, the preventive of a frozen hydrant is to keep water out of the barrel. This sometimes is a difficult matter, for various reasons. Sometimes the waste does not work. It may be clogged, or perhaps the operator does not sufficiently vent the hydrant after using. Sometimes the ground around the hydrant is saturated and will not take any more water. Sometimes the ground around the hydrant contains water to the extent that it enters through the waste and partially fills the hydrant barrel. Sometimes the valve leaks. Pebbles are caught in the closing and embedded in the leather or rubber packing, thus preventing a tight shut-off. Sometimes, because of a poor quality of rubber or leather, pieces of the same break off. Sometimes the stem becomes warped or strained, and so on.

It is an old story but, nevertheless, true, that hydrant troubles are largely attributable to the misuse and abuse of the hydrant. Originally, a hydrant was an exclusively fire-fighting adjunct; now it is an appurtenance for public convenience. Tom, Dick, and Harry use it for the most trivial purposes. It is used by boys to flood vacant lots for skating purposes. It is used by the owners of automobiles to wash their machines. One case I have in mind is where, on a Sunday morning, no less than six or eight cars, mostly flivvers, were lined up waiting their turn at a hydrant to receive their weekly wash. Some one in the neighborhood had a reducing cap and a garden hose. As for the wrench, it was a Stillson. I have seen the eye of a pick used to turn the operating nut of a hydrant. I have seen a junk collector descend from his team and open a hydrant on the public highway, fill a pail and water his horse. I have heard of a teamster who stopped along a main thoroughfare and opened a hydrant, filled his pail repeatedly and with a sponge washed his wagon.

I cannot see why a hydrant is not just as much a part of the Fire Department equipment as the hose, the pump, or the ladders, and should not be respected as such. However, it is a condition we are up against and not a theory, and if water will get into hydrant barrels in cold weather, it is our work to remove it if possible, before it turns to ice.

We might utilize the method we take to prevent freezing of our auto-

mobile radiators and use some non-freezing compound like denatured alcohol, calcium chloride, kerosene, glycerine, etc. Certain queries with reference to the use of those substances enter our minds. How shall we confine it to the barrel? What is to prevent its running out through the waste? What effect will it have on the leather or rubber packing? What proportion shall we use, not knowing how much water will accumulate in the barrel?

There are some things we can do with a certainty of results, however. If ground water backs into the hydrant we can connect the waste with a sewer. If there is no sewer nearby we can plug the waste hole and visit the hydrant frequently, test it for water or ice, and remove either one or the other.

In Boston, we have a number of underground hydrants, called Lowrys. To use one, a cover is removed and a chuck screwed on the barrel. The top of the barrel is open and is a little below the level of the street. Surface water frequently flows into it, especially during a thaw. This water will then freeze and the hydrant cannot be opened by the firemen. Our hydrant men prevent the freezing in many cases by dropping a handful of rock salt into the barrel. Whether that method would function successfully in a post hydrant, is a question worth considering. The reason for using it in our Lowrys and not in our posts is that we can watch its action in the Lowry barrel, but not in the post. Of course, the salt is efficacious only where there is little water in the bottom of the barrel. If the barrel should fill up, the handful of salt would either dissolve or remain at the bottom and the water would freeze at the top of the barrel.

There is really no panacea for frozen hydrants. The one dependable method is frequent inspection. Eternal vigilance! Keeping in touch with the fire department and having some arrangement with the sewer and street cleaning departments, to the end that immediately after the use of a hydrant it will be examined and put in condition for use, is advisable. The aid of the police should also be enlisted to the extent of their reporting the use of any hydrant that comes under their observation.

As for protection of hydrants from automobiles, nothing can be done except to relocate those that are placed in obviously exposed locations. In extremely dangerous situations, posts may be set to act as buffers on either side or in front of the hydrant. These posts may be made of old iron pipe filled with concrete and painted black and white, or yellow. It may readily be understood that there cannot be too many of these buffers placed throughout the city. There would be objection to them as obstructions and as being unsightly. It is impossible to foretell where and when the next hydrant will be struck and broken by an automobile.

Underground valves do not, as a rule, suffer from frost or other danger. Their position underground, in brick or concrete vaults, serves as a protection. Occasionally, if exposed in an excavation during cold weather it is necessary to cover them. Manure, straw, salt hay, felt or heavy bag-

ging will afford protection. It is quite necessary to keep valve boxes clear of mud and water, especially so when the boxes are small. If the mud or water remains in the boxes during cold weather it freezes and the operation of the valve is delayed. Sometimes this is a serious matter.

Another trouble that has developed in recent years as a by-product of the use of cement grout to fill the joints of granite block pavement is the seeping down through the valve box cover of the liquid grout, filling or partially filling the box and later setting into a rock hard substance that required drills to break up and remove. As a prevention, we fill the spaces in the cover, through which the grout may flow, with paper or jute or clay or sand. A little attention to this matter during the pouring of the grout will save trouble later on.

With regard to service pipes, care should be exercised to see that they are laid at proper depth with reference to frost and where the department lays only to the property line the owner should be made to continue it on his property with the same amount of cover, into his cellar.

There is a tendency among builders to dig shallow trenches inside the property line. To avoid removal of rock, they will sometimes lay the pipe with only a foot or two of cover. This, of course, is a starting-point for a freeze that will run out towards the main in the street, and before water is made to flow in the pipe the water service will have performed a job of thawing. It is often a difficult matter to convince the owner that the ice began to form on his property.

The foregoing is only a bare outline of the measures to be taken in self-defence against some of the accidents and untoward incidents due to the exposed conditions of water pipes and their appurtenances.

Possibly it may stimulate a little constructive thought that will develop into more efficient and economical ways and means of treating the conditions mentioned.

Samuel E. Killam.* Various methods are employed in laying distribution mains in exposed locations, and considerable study should be given to each individual case. The amount of protection required to prevent the water in distribution mains crossing bridges, and in other exposed places, from freezing, depends on the temperature of the air, on the velocity of minimum flow, and on the size of the mains.

Throughout New England and other sections of the country having similar climatic conditions, it appears advisable, in order to lighten the burden of those held responsible for the maintenance of structures and the delivery of an uninterrupted supply of water to all sections of the distribution system, to see that at all bridge crossings and other exposed places the pipe is properly protected.

Many water supplies come from surface sources, and the temperature of the water in the distribution system during the winter months may be but little above freezing.

* Superintendent, Distribution, Metropolitan District Commission, Mass.

If there is a movement of the water at all times, protection will seldom, if ever, be required on pipe 18 in. or more in diameter if the span does not exceed 200 ft. in length. Smaller pipe lines of cast iron or steel in a distribution system require protection.

During the past thirty or forty years many different methods and kinds of materials have been employed in boxing pipes to prevent freezing and rupture in exposed pipe lines. The usual method has been to box around the pipe and fill the space around the pipe with fibrous packing such as oily cotton waste, asbestos, hair felt, mineral wool, tan bark, and the like. Many of these experiments were absolute failures, as the fibrous material became saturated with moisture from improperly constructed covering, leaky joints, or condensation, and the material as well as the water in the mains froze solid.

Other materials, such as salt hay, sawdust, rosin, lampblack, lime, concrete and other non-conducting subtances, have been used with varying success. Any material used as packing that has a tendency to decompose will soon become non-effective if it is not kept dry.

In certain locations where there is considerable moisture, such as street chambers or in chambers which may at times become flooded with water, hay cut on tide water marsh has proven very useful in protecting during the cold weather such structures as valves, meters, and other pipe line appurtenances. The hay should be renewed every second or third year.

Slacked lime also has been effective when placed around service pipes or mains containing dead water such as service pipes for recording gages and small mains used only for fire purposes.

An effective method to prevent exposed structures from freezing is to create a dead air space around the pipe. This may be accomplished successfully when there is considerable flow through the main by enclosing the pipe in a single well-constructed box which may be lined with tar felt, thus creating a dead air space around the pipe.

Other methods of boxing are what is known as double and triple boxing, the double boxing being simply one box built inside of another, creating two dead air spaces. The triple boxing creates three dead air spaces or two dead air spaces with the middle space filled with non-conducting material.

In the Water Division of the Metropolitan District Commission a very effective non-conducting material to prevent water pipes and appurtenances from freezing has been found by filling forms built around structures with a mixture of granulated cork and hot pitch. This material is similar to that used in cold-storage plants to keep the cold in, and has been found equally as good to keep the heat in and the cold out of water-works structures.

This mixture of cork and pitch has been used for insulating mains, service pipes for recording gages when laid near the maximum frost line, and steel meter tanks in which are located meter registers.

This insulating material, unless disturbed, will remain in good con-

dition for many years and retain its effective qualities, as the pitch seals the cork, keeps it from decomposing, and retains the dead air. The first cost of the pitch and cork insulation may be more than other methods but when properly applied and protected will last a lifetime.

CHARLES W. SHERMAN.* Mr. Killam and Mr. Finneran have covered the general subject of exposure of pipes to cold weather, where they cross bridges, in a very complete manner — so much so that there is very little which can be said on the subject.

There is another kind of exposure which neither of them mentioned, which is not ordinarily met with in the experience of the ordinary superintendent, but which does sometimes occur. That is where a pipe has to cross the salt water for a considerable distance to an island to maintain a supply of water. It differs from the crossing of a channel, which is referred to by Mr. Finneran, in that the distance is usually so great that the ordinary inverted siphon enclosed in a box or concrete is entirely out of the question.

I have in mind a case which was referred to me a few years ago as to the practicability of maintaining service to an island off the Maine coast, where the supply was through a 6-in. pipe. The distance there was something over two miles — I forget the details at the moment. But the problem seemed to be, how much heat was in the water passing through that pipe and how much time it would take to give it up to the salt water, which might be at a temperature as low as 27°, or even lower in extreme winter conditions. It was thought, or suggested at least, that if the pipe were left open on the island so as to maintain sufficient velocity of flow through the pipe, the service might be maintained. The information that would have been desired for a satisfactory study of the problem was not to be had; but making assumptions that seemed to be reasonable, and bearing in mind that in all probability something like half the length of the pipe was probably not buried in the mud but was exposed to the salt water, at least on the upper half of the circumference, it seemed probable that water starting at a temperature of 36 or 38 degrees in the pipe would give up all of its remaining heat above the freezing point within an exposure of at most ten minutes in that pipe; and even if a velocity as high as 5 ft. per second could have been maintained, which was out of the question at night time, it would have taken a half-hour or more for the water to travel from the mainland to the island.

We reported we did not think it was feasible under the circumstances to maintain a winter service through the pipe, and I believe the attempt was not made.

PRESIDENT TAYLOR. I might say in that connection that we in New Bedford have had sad experience with a small pipe under salt water, about 900 ft. long, from one island to another, crossing a draw. It con-

* Of Metcalf & Eddy, Consulting Engineers, Boston, Mass.

sequently had to be on the bottom. We tried to maintain a 2-in. lead pipe by simply dropping it and letting it take the contour of the bottom and sink into the mud. We had great difficulty. It froze up every winter. We finally have taken the bull by the horns and spent about $4 000 in 900 ft. of pipe buried at least 4 ft. below the bottom. This is the first winter we have had it under these conditions, and this winter we have had no trouble. But we did have constant trouble trying to maintain a 2-in. water service on the bottom. We tried to keep a tap open on the farther side, but that was not effective; the water froze before it got there.

MR. SHERMAN. In studying this case I looked up all the published reports on such conditions as I could find, and I found, as was naturally the case, a number of cases of frozen pipes reported; and other cases where the distance was very considerable, where the service had been maintained with apparently no difficulty. It seemed almost beyond question that in those cases the pipe must have settled into the mud, probably to a depth of at least 6 in., and perhaps a foot or more. And the indications were that ordinary harbor mud, even with a comparatively few inches of covering over the pipe, but entirely surrounding it, is reasonably efficacious in preventing the transfer of heat from the fresh water in the pipe to the salt water; but that where the pipe is actually exposed to the salt water for any material distance, it is practically impossible to prevent a transmission of the heat sufficient to cause freezing in the pipe.

INDEX OF ADVERTISERS.

	Page
Ambursen Construction Co.	ii
Badger Meter Mfg. Co.	xv
Barbour & Dixon	ii
Barrows, H. K.	ii
Boston Pipe & Fittings Co.	xxvii
Buffalo Meter Co.	x
Builders Iron Foundry	ix
Byers, A. M., Co.	xxvi
Caldwell, Geo. A., Co.	xxvii
Cement Lined Pipe Co.	xxvii
Central Foundry Co.	xliii
Chadwick-Boston Lead Co.	xxxix
Chapman Valve M'f'g Co.	xxxii
Clark, H. W., Co.	xxvii
Coffin Valve Co.	xxx
Conard & Buzby	ii
Dixon, Jos., Crucible Co.	xix
Donaldson Iron Co.	xxxiv
Eddy Valve Co.	xxxiii
Edson Manufacturing Co.	xxxvii
Fairbanks-Morse & Co.	xxi
Fay, Spofford & Thorndike	ii
Ferullo, G., Co.	iii
Fox, John & Co.	xxxvi
Fuller & McClintock	ii
Gamon Meter Co.	xiii
Hayes Pump and Machinery Co.	xix
Hays M'f'g Co.	xli
Hazen & Whipple	ii
Hersey M'f'g Co.	iv
Houdlette, Fred A., & Son	xxvii
Hubbard, W. B. & Sons Co.	xxvii
Kennedy Valve Mfg. Co.	xxix
Kennison, Karl R.	iii
Lead Lined Iron Pipe Co.	xxxvi
Leadite Co.	xxxviii
Lead-Hydro-Tite	xl
Linder & Meyer	xxv
Lock Joint Pipe Co.	xliii
Ludlow Valve M'f'g Co.	xxxi
Main, Charles T.	ii
Mazzur, F. A. & Co.	xvii
Merrimac Chemical Co.	xxiv
Metcalf & Eddy	ii
Michigan Pipe Co.	Back cover
Mueller Co.	xvi
Murray Iron Works Co.	xx
National Meter Co.	xiv
National Water Main Cleaning Co.	xxx
Neptune Meter Co.	vi
Pierce-Perry Co.	xxvii
Pitometer Company	xxxiv
Pittsburgh Meter Co.	vii
Power Equipment Co.	xix
Ray Engineering Co.	xix
Rensselaer Valve Co.	xxxi
Ross Valve M'f'g Co.	xxx
Simplex Valve & Meter Co.	xii
Smith, The A. P., M'f'g Co.	xxxvi
Starkweather & Broadhurst	xviii
Sumner & Dunbar	xxvii
Symonds, Henry A.	iii
Thomson Meter Co.	v
Thorpe, Lewis D.	iii
Turbine Equipment Co.	xxii
Union Water Meter Co.	xi
U. S. Cast Iron Pipe and Foundry Co.	xxxv
Wallace & Tiernan	xxiii
Ware Coupling and Nipple Co.	xxvii
Warren Foundry and Pipe Co.	xxxvii
Weston & Sampson	ii
Wood, R. D., & Co.	xxviii
Worthington Pump and Machinery Corp.	viii

(Classified index on page xliv)

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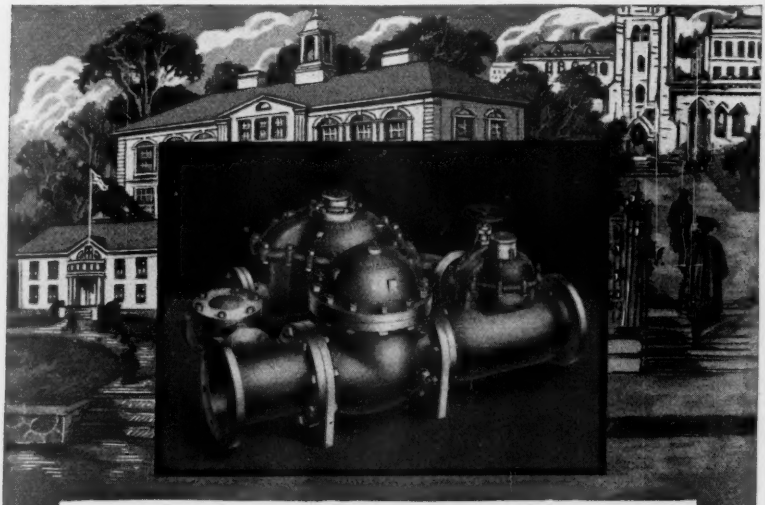

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are worth less than half the value of the property this Meter protects

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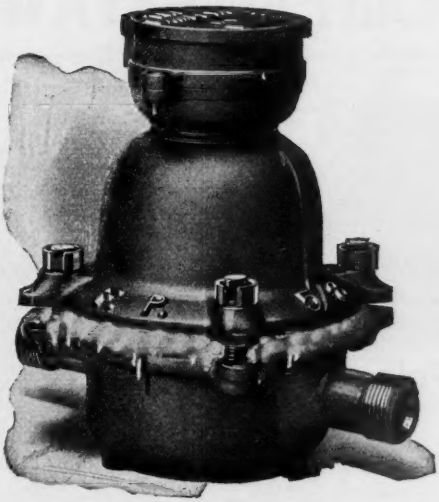

FROZEN!—but not damaged

Here is an actual photograph of a LAMBERT Frost-proof Meter which has been frozen to an extent that would put the ordinary meter completely out of commission.

This is made possible by a patented, non-corrosive yielding bolt device which allows the upper and lower casing, disc chamber and gear train to part without damaging the meter in any way. Five minutes' labor the only repair cost.

The expense and annoyance from frozen water meters can be eliminated for all time through the installation of the LAMBERT Frost-proof.

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The Voice of a Hundred Cities---

NOT on our word alone, but on the testimony of a hundred cities, base your judgment of the superiority of Neptune Trident Meters. Out of the experiences of municipalities—large and small—in all parts of the country, take the figures which show the economy, and the necessity, for a Neptune Metered Water Supply.

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But let the voice of Neptune users tell you the actual story of the Trident in service. The saving in water; reduction of pumpage; conservation of water resources; increase in water revenues; lowered cost and increased supply to water consumers; accuracy, long service and minimum maintenance cost of the meter itself—this is the story the cities tell. There are over 2,750,000 Neptune Trident Meters in service. Study the results where they are being used.

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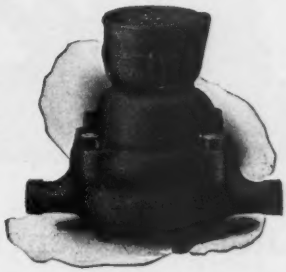

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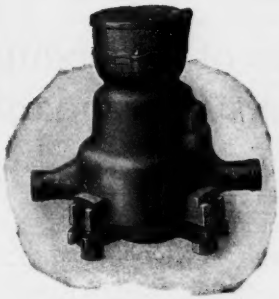

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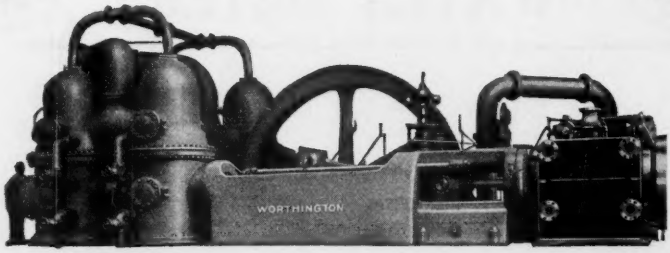

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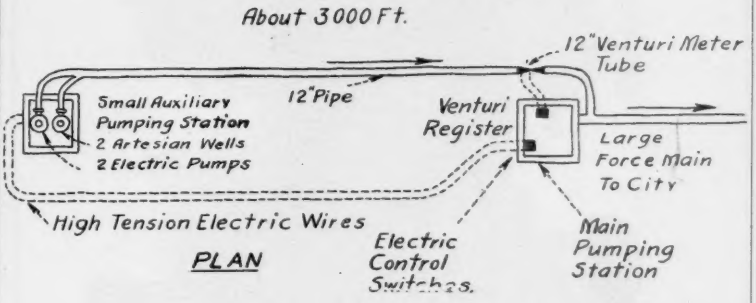

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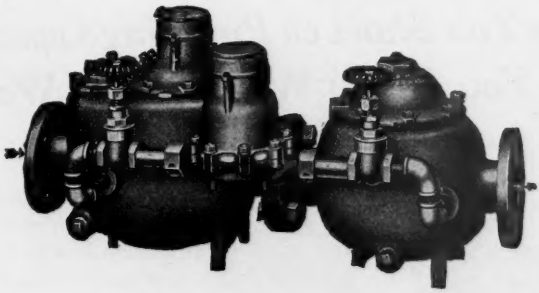

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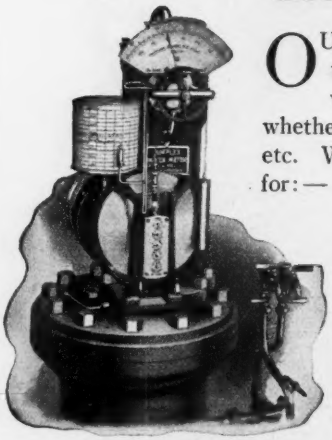

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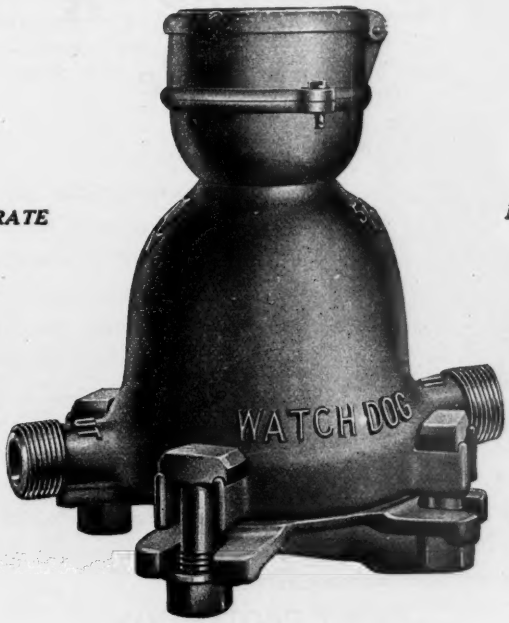

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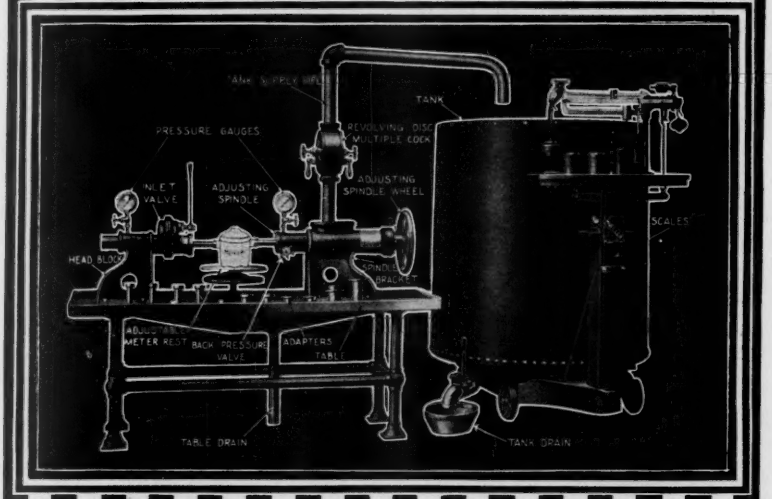

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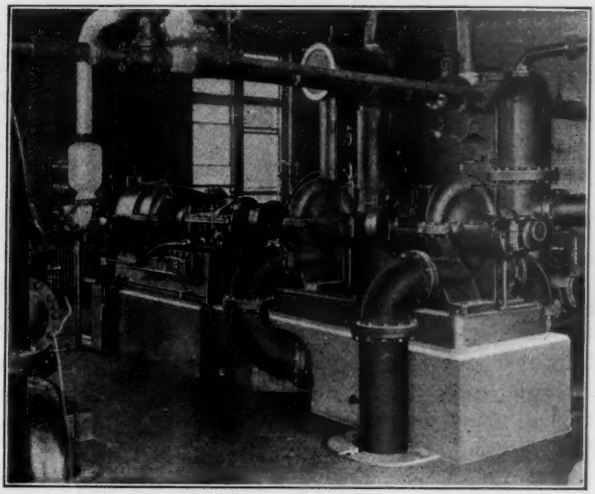
First. — We make a specialty of furnishing Complete Water-Works Pumping Units of all types.

Second. — Total responsibility of installation is assumed by us.

Third. — We relieve the purchaser of every detail and turn the complete unit over to him under actual operation and with guarantee.

Fourth. — Every unit installed to date has exceeded its guarantee and has been completely accepted.



Turbine-driven Pump at the Arlington Station of the Metropolitan Water Works, Boston, Mass.

F. A. Mazzur & Co.

141 MILK STREET, BOSTON

Centrifugal Water Works Pumps

BUILT FOR THE LAST 70 YEARS AT BALDWINSVILLE, N. Y.

By Morris Machine Works

Reliable **Substantial** **Efficient**

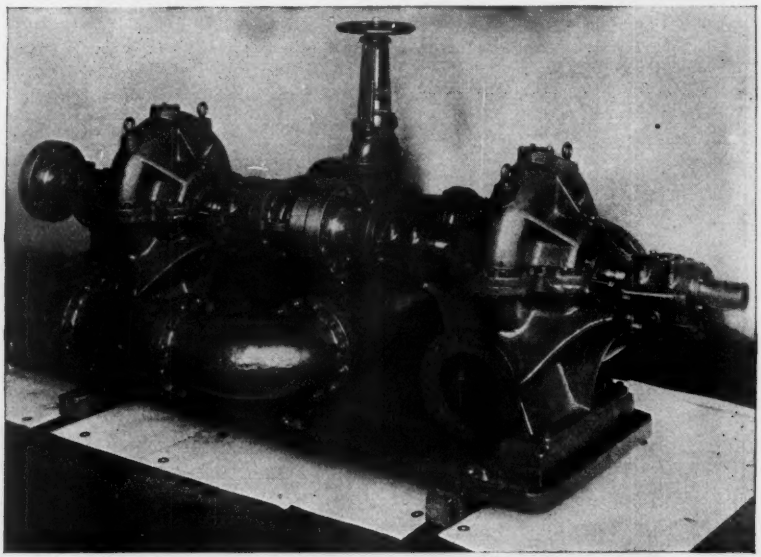


Illustration shows two 3 M.G.D. pumps just furnished as part of complete waterworks equipment to Kennebec Water District, Waterville, Me., to plans and specifications of Metcalf & Eddy, Consulting Engineers, Boston. These pumps will be driven by direct connected Motors and with Gasoline Engines for stand-by service. Arrangement permits single or series operation depending upon head, which varies greatly with capacity required.

We furnish pumps for all heads and capacities, motor turbine or engine driven, and when desired install complete units ready for operation.

Starkweather & Broadhurst, Inc.

ENGINEERS AND CONTRACTORS

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HAYES PUMP AND MACHINERY CO.

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Pumping Plant Contractors

CENTRIFUGAL, POWER, STEAM PUMPS

STEAM TURBINES
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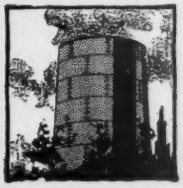
Power Plant Equipment
Steam and Heating Specialties

For new pumping equipment guaranteed by people who will make good, phone, wire or write the above.
Sales Agents for UNION STEAM PUMP CO.



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Water Tanks
Gas Holders
and all other metal surfaces need the protection of
DIXON'S
Silica-Graphite
PAINT
BOOKLET NO. 87-B
JOSEPH DIXON CRUCIBLE CO. Jersey City, N. J.

WE announce our appointment as Sales Representatives of DAYTON-DOWD COMPANY, of Quincy, Ill., Manufacturers of Centrifugal Pumping Machinery. After exhaustive investigation, we present this line of equipment to the Trade in New England as being of the highest grade and thoroughly modern in design and manufacture.

We are prepared to furnish DAYTON-DOWD pumps in all sizes and for all classes of service, in steam, motor, gasoline and belt drive types, and solicit your inquiries, assuring you of our best efforts in your sales and service requirements, and of our appreciation of your continued confidence and patronage.

POWER EQUIPMENT CO.

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MURRAY IRON WORKS CO.

(INCORPORATED 1870)

BURLINGTON, IOWA, U. S. A.

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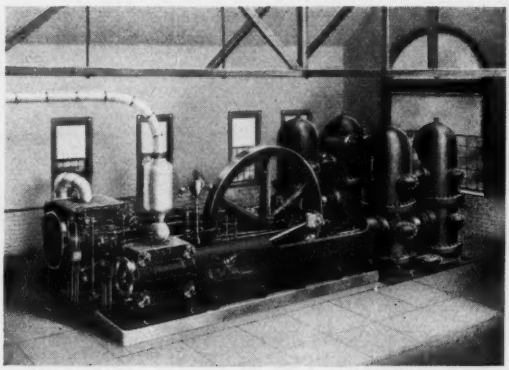

Murray High Duty Crank and Fly Wheel Pumping Engine, Opposed Type

Engineers, Iron Founders, Boiler Makers

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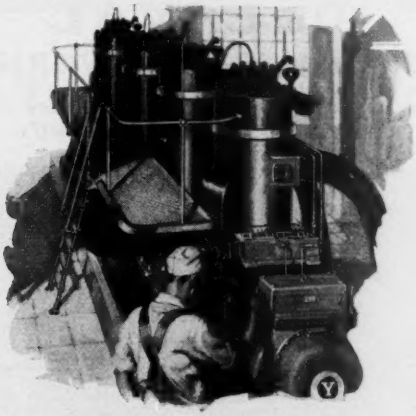
Water-Tube, Fire-Tube and Internal-Furnace Boilers

Builders of Complete Power Plants

PLEASE SEND US YOUR SPECIFICATIONS AND CALLS FOR BIDS



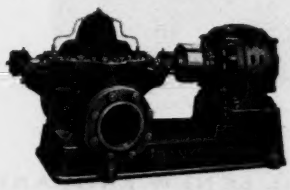
More than 90,000 h.p. *in Pumping Stations alone*

Over 90,000 horsepower of Type "Y" Engines are today furnishing power for pumping stations and the number is constantly increasing.

This steady change to Type "Y" Diesel power is the natural result of operation economies that have been accomplished during the past ten years.

In waterworks service, the Type "Y" Diesel effects a saving of 50 to 75 per cent of the cost of steam or purchased power — with absolute dependability and less attention than is required in operating a steam plant.

The Type "Y" Diesel is a 2-cycle valveless airless injection cold starting engine — actually simpler than even a slide valve steam engine.



More than 800,000 horsepower of Fairbanks-Morse oil engines are in daily operation in industrial, central station, and marine service. This unequaled acceptance points not alone to the economy of Diesel power but to the proved dependability of the Fairbanks-Morse Type "Y" Engine.

And the pumps, too, should be Fairbanks-Morse.

Just as electric motor development took a great step ahead when Fairbanks-Morse originated ball bearing motor construction, so the use of ball bearings in the new "Fig. 850" and "Fig. 870" Fairbanks-Morse Pumps has paved the way to higher pumping efficiencies and new economies. This is simply representative of the advanced construction that is found in Fairbanks-Morse Pumps for practically every duty. Centrifugal or piston types; motor, steam or oil engine drive: gear driven, belt driven, or direct-connected.

One of our engineers will gladly give you facts and figures. Detailed information on Diesel Engines, Pumps, or combined units, will be mailed on request.

FAIRBANKS, MORSE & CO., Boston

Manufacturers Oil Engines, Pumps and Electrical Machinery

Twenty-eight branches in the United States, each with a service station.

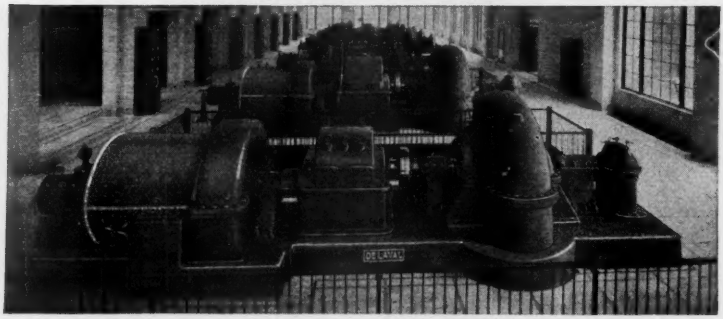
FAIRBANKS-MORSE

Diesel Engines - Pumps

DE LAVAL

CENTRIFUGAL WATER WORKS PUMPS

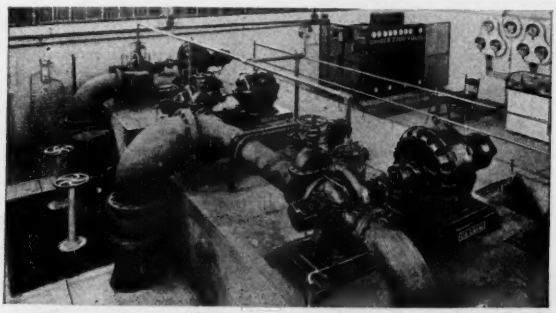
Supply 200 American Municipalities with over 5,000,000,000 gallons daily.



FAIRMOUNT PUMPING STATION, CLEVELAND, OHIO.

The largest Turbine driven pumping station in the United States. Total capacity 300 million gallons per day against heads from 85 ft. to 400 ft.

Cleveland has thirteen units installed totalling 600 million gallons per day. A fourteenth unit on order will have the unprecedented capacity of 60 million gallons against 270 ft. maximum head. Chicago has fourteen DE LAVAL units installed and on order totalling nearly 900 million gallons per day.



A TYPICAL SMALL DE LAVAL STATION, BROCKTON, MASS.

The De Laval Company announces their New England representation was transferred January 15, 1925, to

TURBINE EQUIPMENT CO. *of* NEW ENGLAND
CHAMBER OF COMMERCE BUILDING
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This company is under the direction of F. R. C. Boyd, President, who has been connected with De Laval representation in New England for over fifteen years.

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A basic, uniform product which has been used successfully by the leading water filtration plants in New England for many years.

Our location and shipping facilities place us in a position to offer insurpassable service and make us the logical source of supply for all filter plants in New England.

The aid and advice of our technical staff has often proved of great value to our customers. It is always at their service.

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Works:

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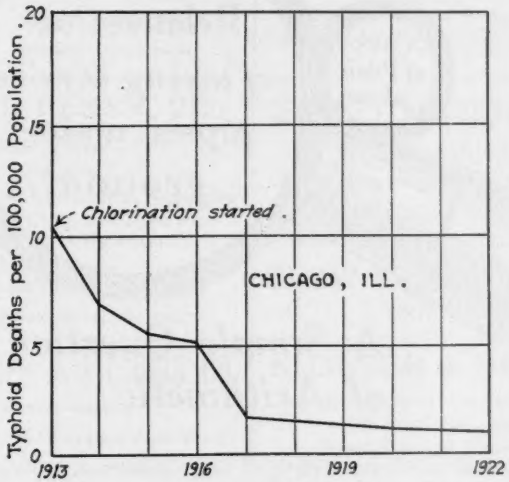

DIAGRAM SHOWS REDUCTION IN TYPHOID FEVER DEATH RATE AFTER INSTALLATION OF CHLORINE

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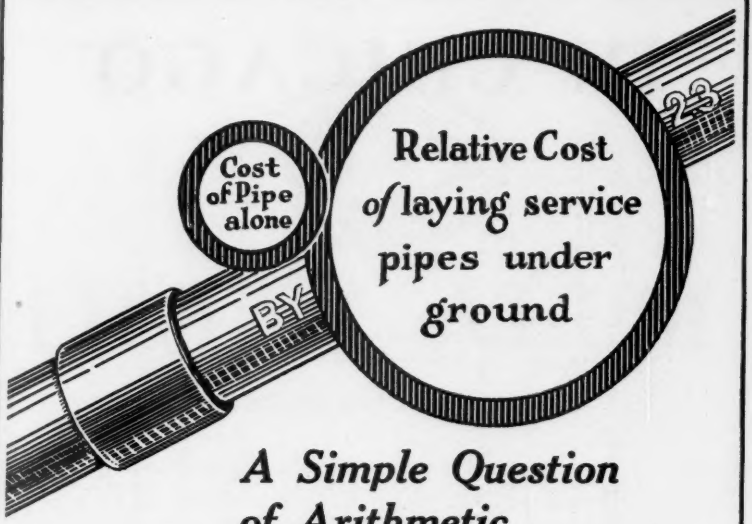

A Simple Question of Arithmetic

The cost of a length of service pipe is trifling compared with the cost of laying it. In case of failure of the pipe, the loss of water, labor of digging up and renewing a pipe, still further multiplies the installation cost.

The lasting quality of the pipe, depending on its rust-resistance, is therefore the first thing to be considered by the majority of experienced water works engineers and superintendents. Hence the extensive use of Byers pipe for underground water service.

The chemical and physical properties of genuine wrought-iron and their bearing on the question of rust-resistance, are interestingly dealt with in Byers Bulletin No. 6-A. Write to A. M. Byers Company, Pittsburgh, Pa., for a free copy.

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Look for the Name and Year rolled in every length

CLARK METER BOXES
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Engineers, Iron Founders and Machinists

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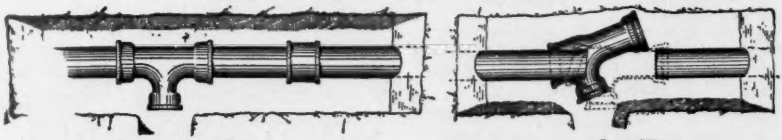
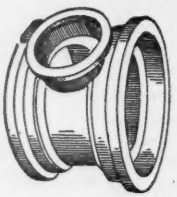
PUMPING ENGINES

Cast Iron Pipe

CUTTING-IN TEES



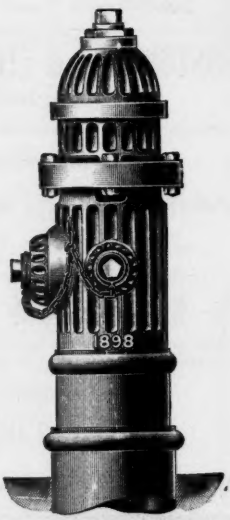
Old Way *Our Way*



Connections economically and easily made with one fitting. Saves sleeve, cuts, lead and unnecessary work and material.

"Reduced Specials"

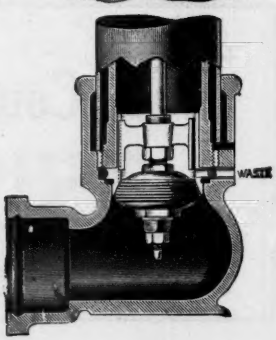
Cost of fittings reduced from 25% to 50%. Full strength. Deep bells. Convenient to handle. Sold by the piece.



Mathews Fire Hydrants

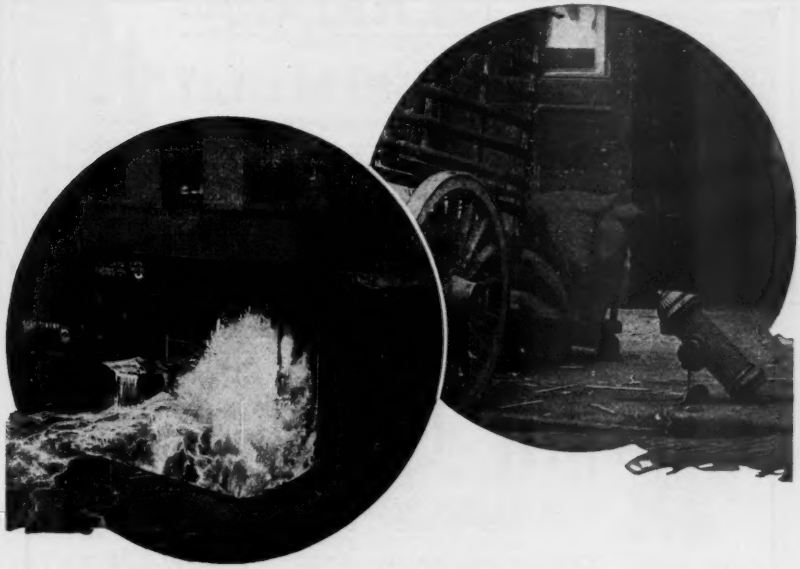
A half century of use has established their reputation as being the most economical, durable and simple hydrant.

Number in use exceeds total of all other makes combined.



Gate Valves

R. D. WOOD & CO. STANDARD
DOUBLE DISK
ANTI-FRICTION
EXTRA WEIGHT, FINISH
AND MATERIAL



Are Your hydrants flood proof?

Accidents will happen. And the exposed position of a fire hydrant renders it particularly subject to mishaps which, unless properly provided against, cause loss of water, property damage and even danger to life.

The Kennedy " Newtype " Dire Hydrant is designed to automatically and effectively prevent loss of water and consequent damage due to flooding or breaking. This advantage is secured without special mechanism in the " Newtype " Fire Hydrant so that even after a long period of inaction its operation is assured.

The flood-proof feature is only a single one of the many special characteristics of the Kennedy " Newtype " Fire Hydrant. Its construction also eliminates danger of breakage from freezing, permits easy inspection and removal of internal working parts without in any way disturbing the standpipe, digging up the street or disconnecting the main, and assures low service cost by simplicity, interchangeability and high quality. Our Hydrant Bulletin fully explains these features. Send for it.

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FILTERS
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We make **Pressure Regulating Valves** for all purposes, steam or water.

Our **Feed-Water Filter** will keep oil out of your boiler.

We can interest you if you use a condenser.

Water Engines for Pumping Organs

THE ROSS VALVE MFG. CO.

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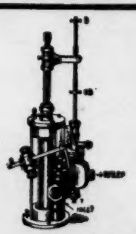

Standard for pumping church or parlor organs. Ask your organ builder for it or write us.

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Sluice Gates, Gate Valves and Fire Hydrants

Health and Protection First

Water delivered through dirty pipes may be a MENACE.

Incrusted water pipes mean inefficiency and loss of Fire Protection.

We Guarantee the Results of Our Method of Cleaning.

WRITE US.

National Water Main Cleaning Co.

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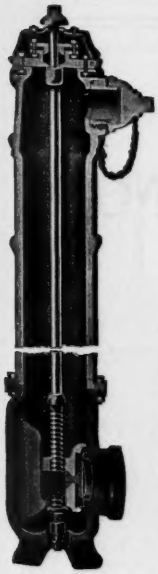


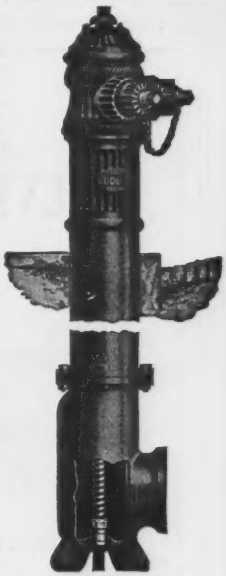
LUDLOW VALVE MFG. CO.

MANUFACTURERS OF

VALVES and FIRE HYDRANTS

This hydrant is anti-freezing, because when the drainage is good no water is left in it to freeze.

The drip is directly in the bottom of the hydrant and drains perfectly. It is protected by its valve, which never leaves its socket and cannot be clogged.



DOUBLE AND SINGLE GATE **VALVES,** ALSO CHECK **VALVES,** FOOT **VALVES.**

FIRE **HYDRANTS.**

YARD, WASH, AND FLUSH **HYDRANTS.**

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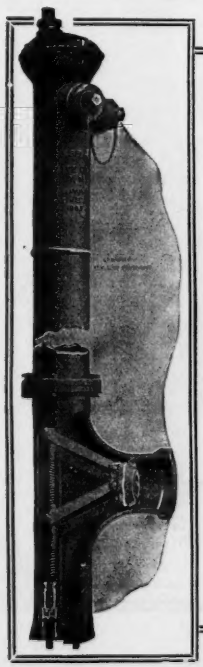

The Knuckle Joint Principle in Genuine "Rensselaer" Improved "Corey" Fire Hydrants—Means Ease of Operation

BECAUSE this principle gives great power to open or close the gate just when it is needed, and speed in movement when power is unnecessary.

The first turn of the spindle, when the gate is open, moves the valve nearly two inches, after which the speed decreases and power throughout the knuckle joint increases, until at the time of closing the valve moves scarcely one-sixteenth of an inch at each turn of the spindle, eliminating danger from water hammer when closing hydrant.

The gate is closed very tight with slight application of power to the wrench by the operator. The drip valve in the Corey Fire Hydrant prevents freezing. No accident or damage to property can occur with this hydrant by flooding the streets where runaway teams or other accident breaks off or otherwise injures the hydrant standpipe, if hydrant was properly closed at time of accident.

It will be readily seen that the hydrant gate is held in position when shut by the four arms forming braces between the back of the hydrant and the seat, consequently the hydrant barrel can be broken completely off above the ground, but the valves remain tight.

Write for copy of our Hydrant Book No. 9.

CHARLES L. BROWN,
New England Sales Manager, Lock Box 2, Northboro, Mass.

RENSSELAER VALVE COMPANY
TROY, N. Y.

THE CHAPMAN VALVE MANUFACTURING COMPANY

Manufacturers of

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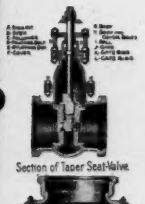
EDDY VALVE CO.

WATERFORD, NEW YORK, U.S.A.

PATENT RUBBER FACED

EDDY FIRE HYDRANT



Section of Taper Seat-Valve.

Hydrant with Independent Nozzle Cut-off.

Section of Parallel Seat-Valve.

Section of Vertical Check-Valve.

Section of Vertical Foot-Valve.

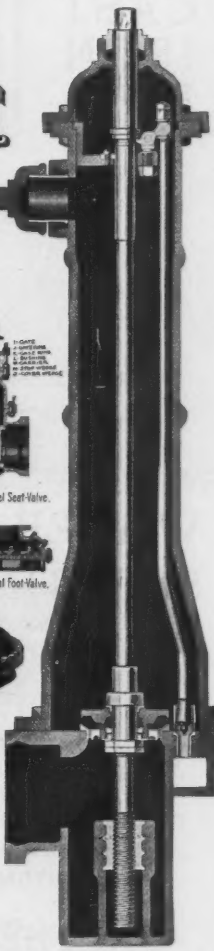
Horizontal Check-Valve.

Vertical Foot-Valve.

Hydrant with Water Crane Attachment.

Indicator Post.

Water Crane with Automatic Drip Valve.



VALVE OPEN – DRIP CLOSED.

All Goods made by the EDDY VALVE COMPANY are manufactured exclusively at WATERFORD, N.Y., U.S.A.

VALVE CLOSED – DRIP OPEN.

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DONALDSON IRON CO.,

MANUFACTURERS
...OF...

CAST IRON PIPE

...AND ..

Special Castings for Water and Gas.
Also Flange Pipe, Street Castings,
Manhole Heads and Covers, etc.

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LEHIGH COUNTY, PA.

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WATER WORKS SUPERINTENDENTS!

Is your per capita consumption too high?

Do you account for less than 85% of your pumpage?

Are you receiving full revenue from your manufacturing consumers?

If any of these problems confront you, write us at once, without obligation, and let us tell you about our PITOMETER SURVEYS.

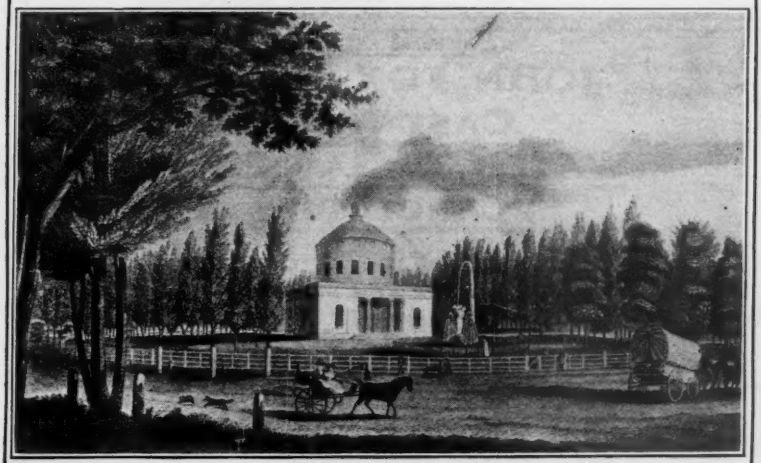
THE PITOMETER COMPANY

Engineers

50 CHURCH STREET, NEW YORK CITY, N. Y.

Philadelphia is most bountifully provided with fresh water, which is showered and jerked about, and turned on, and poured off, everywhere. The water-works, which are on a height near the city, are no less ornamental than useful, being tastefully laid out as a public garden, and kept in the best and neatest order. The river is dammed at this point, and forced by its own power into certain high tanks or reservoirs, whence the whole city, to the top stories of the houses, is supplied at a very trifling expense.

—"*American Notes*" *by Charles Dickens.*



Old Pumping Station, Philadelphia

In 1842 Charles Dickens wrote the above description of the Philadelphia Water Works. At that time cast iron pipe, in Philadelphia, had been delivering water faithfully for 25 years. Nor was its usefulness nearly over. In 1915 the pipe illustrated was removed, though still in good condition after almost a century of service, to make way for a line of larger capacity.

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for their service connections

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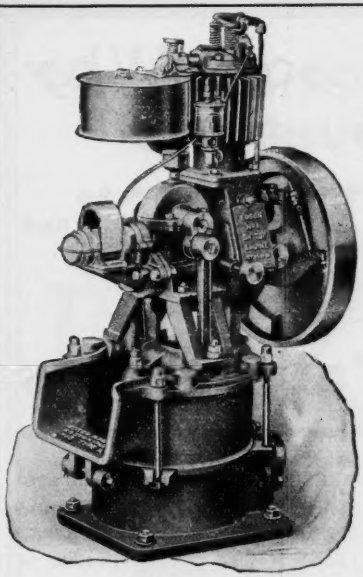

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YOU SHOULD USE

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Registered U. S. Patent Office

FOR

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1. **DURABILITY.** Leadite joints increase in strength with age.
2. **NO CAULKING.** Leadite joints require no caulking, because the Leadite adheres to the pipe, making a water-tight bond.
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P. E. KELLY, New England Representative

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WITH

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AND CUT YOUR EXPENSES

50% FIRST COST

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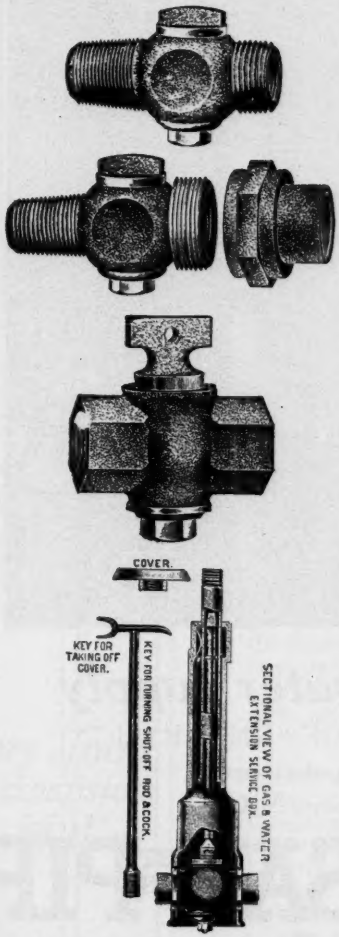

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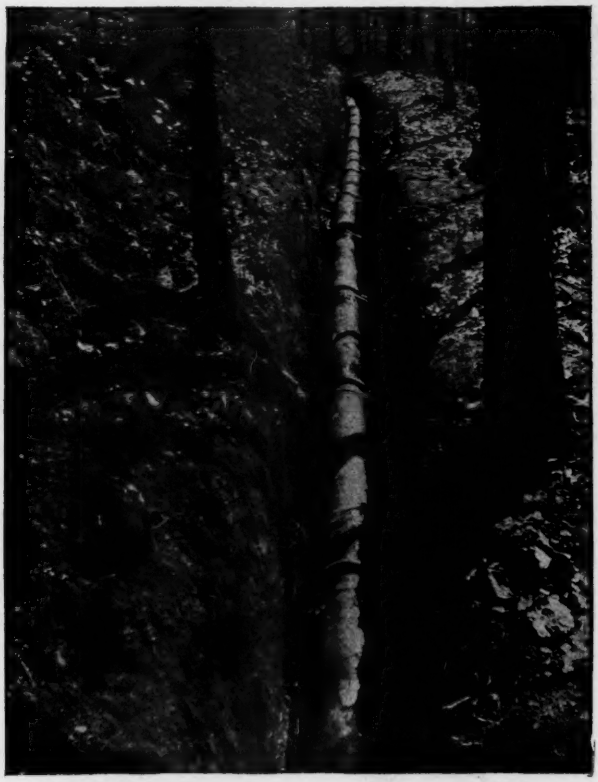

Dependable water supply

16,000 FEET OF "UNIVERSAL"
giving perfect service
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no packing no calking no bell holes

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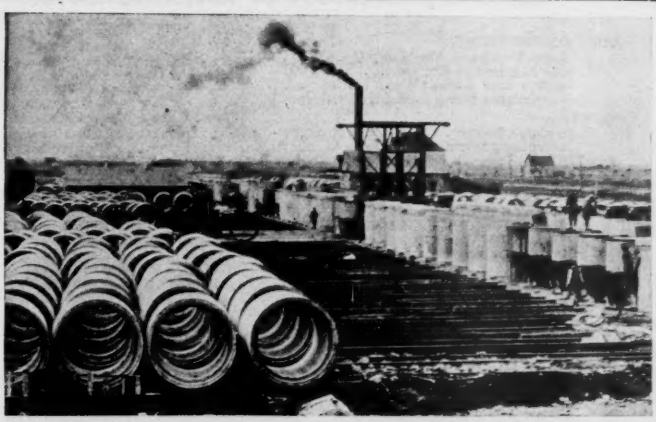

A Few Important Statistics

THE concrete mixture varies according to the materials at hand, but generally approximates 1:1½: 2½.

All forms are steel, held by cast-iron rings insuring great accuracy and especial smoothness, so important in water lines.

Reinforcement varies in amount with the diameter of the pipe and the hydrostatic head under which it operates, and is figured at from 10,000 to 12,000 pounds per square inch, without giving any value to the concrete.

Internal diameters vary from 12 to 108 inches. Up to 72 inches in diameter the pipes are generally made in 12-foot lengths; above 72 inches in diameter 8 to 10-foot lengths.

"Every Joint an Expansion Joint"

LOCK JOINT
Reinforced
Concrete Pipe

Lock Joint Pipe Co., 17 Rutledge Ave.,
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CLASSIFIED DIRECTORY OF ADVERTISEMENTS.

PAGE.

AIR COMPRESSORS.
Hayes Pump and Machinery Co. . . . xix
Ray Engineering Co. . . . xix
Murray Iron Works Co. . . . xx
Worthington Pump & Machinery Corp. . . . viii

ALUM.
Linder & Meyer . . . xxv
Merrimac Chemical Co. . . . xxiv

BOILER SETTINGS.
Starkweather & Broadhurst . . . xviii
Boston Pipe & Fittings Co. . . . xxvii

BOILERS, STEAM.
Mazzur, F. A., & Co. . . . xvii
Murray Iron Works Co. . . . xx
Ray Engineering Co. . . . xix
Starkweather & Broadhurst . . . xviii

BRASS GOODS.
(See also Pipe, Brass.)
Boston Pipe & Fittings Co. . . . xxvii
Caldwell, George A., Co. . . . xxvii
Cement Lined Pipe Co. . . . xxvii
Hays Mfg. Co. . . . xli
Hubbard, W. B., & Sons Co. . . . xxvii
Mueller Co. . . . xvi
Pierce-Perry Co. . . . xxvii
Sumner & Dunbar . . . xxvii
The A. P. Smith Mfg. Co. . . . xxxvi
Union Water Meter Co. . . . xi
Ware Coupling & Nipple Co. . . . xxvii

CALKING MACHINERY AND TOOLS.
Mueller Co. . . . xvi
The A. P. Smith Mfg. Co. . . . xxxvi

CAST IRON PIPE. (See Pipe, Cast Iron.)

CEMENT LINED PIPE. (See Pipe, Cement Lined.)

CHEMICAL FEED APPARATUS.
Wallace and Tiernan Co., Inc. . . . xxiii

CHEMICALS FOR WATER PURIFICATION.
Linder & Meyer . . . xxv
Merrimac Chemical Co. . . . xxiv

CHLORINATORS.
Wallace & Tiernan Co., Inc. . . . xxiii

CHLORINE, LIQUID.
Linder & Meyer . . . xxv

CLEANING WATER MAINS.
National Water Main Cleaning Co. . . . xxx

COCKS, CURB AND CORPORATION.
Boston Pipe & Fittings Co. . . . xxvii
Caldwell, George A., Co. . . . xxvii
Hays Mfg. Co. . . . xli
Mueller Co. . . . xvi
Pierce-Perry Co. . . . xxvii
Sumner & Dunbar . . . xxvii
The A. P. Smith Mfg. Co. . . . xxxvi
Union Water Meter Co. . . . xi

CONCRETE PIPE.
(See Pipe, Concrete.)

CONDENSERS.
Hayes Pump and Machinery Co. . . . xix
Starkweather & Broadhurst . . . xviii
Worthington Pump & Machinery Corp. . . . viii

CONSTRUCTION EQUIPMENT.
Edson Mfg. Corp. . . . xxxvii

CONTRACTORS.
Ferullo, G., Co. . . . iii
National Water Main Cleaning Co. . . . xxx

COPPER SULPHATE.
Linder & Meyer . . . xxv

CURB BOXES.
Caldwell, George A., & Co. . . . xxvii
Clark, H. W., Co. . . . xxvii
Hays Mfg. Co. . . . xli
Mueller Co. . . . xvi
Sumner & Dunbar . . . xxvii

CURB AND VALVE BOX FINDERS.
Caldwell, George A., Co. . . . xxvii

DIAPHRAGMS, PUMP.
Edson Mfg. Corp. . . . xxxvii

ENGINEERS.
Ambursen Construction Co. . . . ii
Barbour & Dixon . . . ii

CLASSIFIED DIRECTORY OF ADVERTISEMENTS *(Continued)*.

ENGINEERS — *Continued* — PAGE

Barrows, H. K. . . . ii
Conard & Buzby . . . ii
Fay, Spofford & Thorndike . . . ii
Fuller & McClintock . . . ii
Hazen & Whipple . . . ii
Kennison, Karl R. . . . iii
Main, Charles T. . . . ii
Metcalf & Eddy . . . ii
Symonds, Henry A. . . . iii
Thorpe, Lewis D. . . . iii
Weston & Sampson . . . .

ENGINES.
(See Pumps and Pumping Engines.)

ERECTORS, WATER WORKS AND POWER MACHINERY.
Hayes Pump and Machinery Co. . . . xix
Mazzur, F. A., Co. . . . xvii
Power Equipment Co. . . . xix
Starkweather & Broadhurst . . . xviii
Turbine Equipment Co. . . . xxii

FEED WATER HEATERS.
Hayes Pump and Machinery Co. . . . xix
Starkweather & Broadhurst . . . xviii
Worthington Pump & Machinery Corp. . . . viii

FILTER RATE CONTROLLERS AND GAGES.
(See Rate Controllers.)

FILTERS AND WATER SOFTENING PLANTS.
Ross Valve Mfg. Co. . . . xxx

FILTRATION PLANT EQUIPMENT.
Builders Iron Foundry . . . ix
Wallace & Tiernan Co., Inc. . . . xxiii

FLEXIBLE JOINTS.
U. S. Cast Iron Pipe and Foundry Co. . . . xxxv

FURNACES, ETC.
Mueller Co. . . . xvi
The A. P. Smith Mfg. Co. . . . xxxvi
The Leadite Co. . . . xxxviii

GATE VALVES. (See Valves.)

GAGES, SURFACE, RESERVOIR AND SPECIAL WATER WORKS.
Builders Iron Foundry . . . ix
Clark, H. W., Co. . . . xxvii

GRIP PIPE FITTINGS.
Ware Coupling & Nipple Co. . . . xxvii

HOSE, SUCTION AND CONDUCTION.
Edson Mfg. Corp. . . . xxxvii

HYDRANTS, FIRE.
Chapman Valve Mfg. Co. . . . xxxii
Coffin Valve Co. . . . xxx
Eddy Valve Co. . . . xxxiii
Fox, John, & Co. . . . xxxvi
Kennedy Valve Mfg. Co. "Newtype" . . . xxix
Ludlow Valve Mfg. Co. . . . xxxi
Rensselaer Valve Co. "Corey" . . . xxxi
The A. P. Smith Mfg. Co. . . . xxxvi
Wood, J. D., & Co. . . . xxviii

HYDRANTS, SPRINKLING AND FLUSHING.
Mueller Co. . . . xvi

INSPECTION OF MATERIALS.
Conard & Buzby . . . ii

LEAD.
Chadwick-Boston Lead Co. . . . xxxix

LEAD PIPE.
(See Pipe, Lead.)

LEAD WOOL.
Chadwick-Boston Lead Co. . . . xxxix

LEAK FINDERS.
Clark, H. W., Co. . . . xxvii
Pitometer Co. . . . xxxiv

LIME.
Linder & Meyer . . . xxv
Merrimac Chemical Co. . . . xxiv

LIQUID CHLORINE.
(See Chlorine, Liquid.)

METERS.
Badger Meter Mfg. Co. . . . xv
Buffalo Meter Co. . . . x
Builders Iron Foundry . . . ix
Gamon Meter Co. . . . xiii
Hersey Mfg. Co. . . . iv
National Meter Co. . . . xiv
Neptune Meter Co. . . . vi

CLASSIFIED DIRECTORY OF ADVERTISEMENTS *(Continued)*.

	PAGE
METERS — *Continued*	
Pitometer Co.	xxxiv
Pittsburgh Meter Co.	vii
Simplex Valve & Meter Co.	xii
Thomson Meter Co.	v
Union Water Meter Co.	xi
Worthington Pump and Machinery Corp.	viii
METER COUPLINGS.	
Clark, H. W., Co.	xxvii
Mueller Co.	xvi
METERS. (VENTURI TYPE).	
Builders Iron Foundry	ix
National Meter Co.	xiv
Simplex Valve & Meter Co.	xii
METER BOXES.	
Clark, H. W., Co.	xxvii
METER TESTERS.	
Clark, H. W., Co.	xxvii
Mueller Co.	xvi
OIL ENGINES.	
Fairbanks-Morse & Co.	xxi
Hayes Pump and Machinery Co.	xix
Worthington Pump and Machinery Corp.	viii
OIL, GREASE, ETC.	
Dixon, Jos., Crucible Co.	xix
PAINT.	
Dixon, Jos., Crucible Co.	xix
PIPE, BRASS.	
Boston Pipe & Fittings Co.	xxvii
Hubbard, W. B., & Sons, Co.	xxvii
Pierce-Perry Co.	xxvii
Sumner & Dunbar	xxvii
PIPE, CAST IRON (AND FITTINGS).	
Builders Iron Foundry	ix
Central Foundry Co.	xlii
Donaldson Iron Co.	xxxiv
Fox, John, & Co.	xxxvi
Houdlette, Fred A., & Son	xxvii
U. S. Cast Iron Pipe and Foundry Co.	xxxv
Warren Foundry and Pipe Co.	xxxvii
Wood, R. D., & Co.	xxviii
PIPE, CEMENT LINED.	
Cement Lined Pipe Co.	xxvii
Union Water Meter Co.	xi
PIPE, CONCRETE.	
Lock Joint Pipe Co.	xliii
PIPE COVERING — WOODEN FOR STEAM PIPING.	
Michigan Pipe Co.	Back Cover
PIPE CUTTING MACHINES.	
The A. P. Smith Mfg. Co.	xxxvi
PIPE JOINTING MATERIAL.	
Dixon, Jos., Crucible Co.	xix
Lead-Hydro-Tite	xl
The Leadite Co.	xxxviii
PIPE, LEAD.	
Chadwick-Boston Lead Co.	xxxix
PIPE, LEAD LINED.	
Lead Lined Iron Pipe Co.	xxxvi
PIPE LOCATORS.	
Clark, H. W., Co.	xxvii
PIPE PUSHERS.	
Clark, H. W., Co.	xxvii
PIPE, TIN LINED.	
Lead Lined Iron Pipe Co.	xxxvi
PIPE, UNIVERSAL.	
Central Foundry Co.	xlii
PIPE, WOOD.	
Michigan Pipe Co.	Back Cover
PIPE, WROUGHT IRON AND STEEL.	
Boston Pipe & Fittings Co.	xxvii
Byers, A. M., Co.	xxvi
Hubbard, W. B., & Sons Co.	xxvii
Pierce-Perry Co.	xxvii
Sumner & Dunbar	xxvii
PITOMETERS.	
Pitometer Co.	xxxiv
PRESSURE REGULATORS.	
Caldwell, George A., Co.	xxvii
Mueller Co.	xvi
Ross Valve Mfg. Co.	xxx
Union Water Meter Co.	xi

CLASSIFIED DIRECTORY OF ADVERTISEMENTS (*Continued*)

PAGE

PROVERS, WATER.
Pittsburgh Meter Co. . . . vii

PUMPS AND PUMPING ENGINES.
Edson Manufacturing Corp. . . . xxxvii
Fairbanks-Morse & Co. . . . xxi
Hayes Pump and Machinery Co. . . . xix
Mazzur, F. A., Co. . . . xvii
Murray Iron Works Co. . . . xx
Power Equipment Co. . . . xix
Ray Engineering Co. . . . xix
Starkweather & Broadhurst . . . xviii
Turbine Equipment Co. . . . xxii
Wood, R. D., & Co. . . . xxviii
Worthington Pump and Machinery Corp. . . . viii

RATE CONTROLLERS.
Builders Iron Foundry . . . ix
Simplex Valve & Meter Co. . . . xii

SERVICE CLAMPS, GALVANIZED.
Mueller Co. . . . xvi

SLEEVES AND VALVES, TAPPING.
Ludlow Valve Mfg. Co. . . . xxxi
Mueller Co. . . . xvi
Rensselaer Valve Co. . . . xxxi
The A. P. Smith Mfg. Co. . . . xxxvi

SODA ASH.
Linder & Meyer . . . xxv
Merrimac Chemical Co. . . . xxiv

STACKS.
Starkweather & Broadhurst . . . xviii

SULPHATE OF ALUMINA.
(See Alum.)

SUPPLIES AND TOOLS.
Boston Pipe & Fittings Co. . . . xxvii
Caldwell, George A., Co. . . . xxvii
Hays Mfg. Co. . . . xli
Hubbard, W. B., & Sons Co. . . . xxvii
Leadite Co. . . . xxxviii
Mueller Co . . . xvi
Pierce-Perry Co. . . . xxvii
Sumner & Dunbar . . . xxvii
The A. P. Smith Mfg. Co. . . . xxxvi

TANKS, STEEL.
Hubbard, W. B., & Sons Co. . . . xxvii
Murray Iron Works Co. . . . xx

TAPPING MACHINES.
Hays Mfg. Co. . . . xli
Mueller Co. . . . xvi
The A. P. Smith Mfg. Co. . . . xxxvi

TAPPING SLEEVES.
(See Sleeves and Valves, Tapping.)

UNIVERSAL PIPE. (See Pipe, Universal.)

VALVE BOXES.
Clark, H. W., Co. . . . xxvii
Rensselaer Valve Co. . . . xxxi
Wood, R. D., & Co. . . . xxviii

VALVE INSERTING MACHINES.
The A. P. Smith Mfg. Co. . . . xxxvi

VALVES, GATE.
Boston Pipe & Fittings Co. . . . xxvii
Chapman Valve Mfg. Co. . . . xxxii
Coffin Valve Co. . . . xxx
Eddy Valve Co. . . . xxxiii
Fox, John, & Co. . . . xxxvi
Kennedy Valve Mfg. Co. . . . xxix
Ludlow Valve Mfg. Co. . . . xxxi
Rensselaer Valve Co. . . . xxxi
Ross Valve Mfg. Co. . . . xxx
Simplex Valve & Meter Co. . . . xii
The A. P. Smith Mfg. Co. . . . xxxvi
Wood, R. D., & Co. . . . xxviii

VALVES, REGULATING.
Mueller Co. . . . xvi
Ross Valve Mfg. Co. . . . xxx
Union Water Meter Co. . . . xi

WATER WASTE DETECTION.
Pitometer Co. . . . xxxiv
Simplex Valve & Meter Co. . . . xii

WOOD PIPE.
(See Pipe, Wood.)

WROUGHT IRON PIPE.
(See Pipe, Wrought Iron and Steel.)

New England Water Works Association.

ORGANIZED JUNE 12, 1882.

APPLICATION FOR MEMBERSHIP.

.....

Full Christian name and surname

residing at.....

(City or Town and State)

desiring to be admitted to Grade of.....

(Junior, Member, Corporate or Associate)

membership in the New England Water Works Association submits the following statement:

I was born at.....

(Place of birth)

.....

(Date of birth)

Have been engaged in the following named work:

.....

.....

.....

.....

.....

(Finally state present occupation)

I will conform to the requirements of membership if elected.

Signed,.....

Address,.....

Dated.....*192* .

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is a quarterly publication, containing the papers read at the meetings, together with reports of the discussions. Many of the contributions are from writers of the highest standing in their profession. It affords a convenient medium for the interchange of information and experience between the members, who are so widely separated as to find frequent meetings an impossibility. Its success has more than met the expectation of its projectors; there is a large and increasing demand for its issues, and every addition to its subscription list is a material aid in extending its field of usefulness. ALL MEMBERS OF THE ASSOCIATION RECEIVE THE JOURNAL IN PART RETURN FOR THEIR ANNUAL DUES; to all others the subscription is four dollars per annum.

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Editor,
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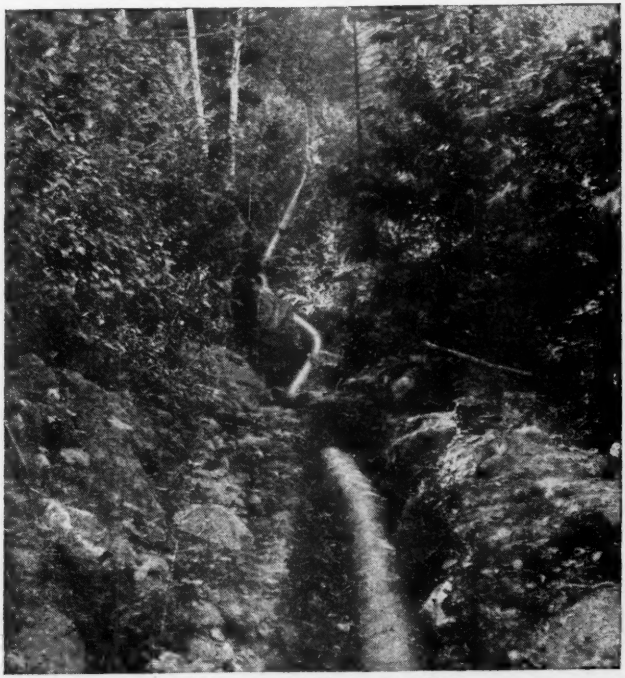
BOSTON, MASS.

The Rust Mill Press
BOSTON, MASSACHUSETTS

MICHIGAN
COMBINATION STEEL AND WOOD
WATER PIPE



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Michigan Pipe Company, BAY CITY MICHIGAN

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